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Effects of triticale-based diets on finishing pig performance and pork quality in deep-bedded hoop barns

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Effects of triticale-based diets on finishing pig performance and pork quality in
deep-bedded hoop barns

by

Zebblin Matthew Sullivan

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of
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Signatures have been redacted for privacy

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CHAPTER 1. GENERAL INTRODUCTION

Triticale (*Xtriticosecale* Wittmack) is a synthetic small grain that results from an intergeneric cross between durum wheat and rye. The name triticale is derived from the two genera involved in the cross - wheat (*Triticum*) and rye (*Secale*). The cross aims to combine the high yield potential and grain quality of wheat with the pest and disease resistance, winter hardiness, and adaptability to marginal environments of rye. When viewed in the context of an integrated crop and livestock system, several attributes make triticale attractive. Addition of an extra crop to the typical corn-soybean rotation of the U.S. Corn Belt could reduce costs, improve distribution of labor and equipment, improve yields of corn and soybeans, provide better cash flow, and reduce weather risks. Lengthening the time between crops on the same ground can decrease the prevalence of some pests, most notably soybean cyst nematode and corn rootworm. Straw from triticale is an excellent source of livestock bedding that becomes available in the late summer when corn stalks stored from the previous fall may be in poor condition. Triticale also provides environmental benefits such as erosion control and improved nutrient recycling. If an additional crop is to be adopted by farmers, it must meet two important criteria. The crop must have a readily accessible market and be profitable to produce. Currently, there is no established market for triticale grain in Iowa.

Triticale has more crude protein and a more balanced amino acid profile than corn. Feedstuffs with a high quality protein (an amino acid profile that more closely matches the needs of the pig) can lower the level of dietary protein fed. This will therefore decrease nitrogen excretion by the pig (NRC, 1998). Triticale has more available phosphorus than corn, which decreases the amount of supplemental inorganic phosphorus in diets (NRC, 1998). Feeding triticale instead of corn as the dietary grain source to swine may reduce the

amount of phosphorus excreted by finishing pigs up to 30% (Sullivan et al., 2005). Previous work indicates triticale has potential to be grown for use as a feed ingredient in swine diets without affecting growth performance (Hale et al., 1985; Jaikaran et al., 1998). However, others have reported adverse growth performance when triticale replaced corn as the dietary grain source (Erickson et al., 1979; Myer et al., 1990). There are several reports of pigs fed triticale-based diets having similar carcass measurements to pigs fed wheat-based, barley-based and corn-based diets (Myer et al., 1996; Jaikaran et al., 1998). Triticale can be substituted for corn or barley in swine diets without compromising meat quality or palatability (Robertson et al., 1999).

Alternative swine production systems have become increasingly popular among pork producers and consumers. Consumers may have a negative perception about current, conventional swine production systems. Producers are attracted to alternative production systems for many reasons. Niche market access, animal welfare concerns, low-capital investments, versatility, health concerns of the producer and environmental considerations are all possible reasons for utilizing alternative swine production systems.

One alternative swine production system that has become prevalent is hoop barns. Hoop barns are also known as hoop structures or simply hoops. A hoop is a Quonset-shaped structure resembling a large tent. The initial cost of hoops for finishing pigs is about one-third that of the initial pig space cost of a confinement building (Honeyman et al., 2001). Animal welfare is better in hoops than confinements (Lay et al., 2000). Pigs finished on bedding have fewer foot and toe lesions (Gentry et al., 2002) and overall injuries (Lay et al., 2000) than those on concrete slats or in non-bedded confinement. Consumer perceptions

about raising pigs in confinement are becoming increasingly negative (Ngapo et al., 2003; Korsching et al. 2004).

In the following experiment, the effects of triticale-based diets in deep-bedded hoop barns on finishing pig performance and pork quality were evaluated and documented.

Thesis Organization

This thesis is divided into a literature review, one paper and a general summary. The following paper was prepared for appropriate submission to the *Journal of Animal Science*.

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CHAPTER 2. LITERATURE REVIEW

Triticale

Introduction

Triticale (*Xtriticosecale* Wittmack) is a synthetic small grain that results from an intergeneric cross between durum wheat and rye. The name triticale is derived from the two genera involved in the cross - wheat (*Triticum*) and rye (*Secale*). The cross aims to combine the high yield potential and grain quality of wheat with the pest and disease resistance, winter hardiness, and adaptability to marginal environments of rye. Following the initial cross between wheat and rye, which results in primary triticale, further crossing with wheat or other triticales is often performed to develop varieties with desired characteristics.

Although the name triticale did not appear in the scientific literature until circa 1935, the first deliberate crossing of wheat and rye occurred in Scotland in 1875 (Wilson, 1876). Initial attempts of crossing wheat and rye resulted in sterile offspring. Fertile offspring were not successfully reared until 1891 (Hackett and Burke, 2004). While fertile triticale was produced in the late 1800's, it would be the mid-twentieth century before this scientific curiosity was developed into a commercially acceptable crop.

Early triticale varieties possessed many unfavorable characteristics including low yield, floret sterility, and seed shriveling. The early varieties were also late maturing, prone to sprouting and tall, which led to lodging problems. These characteristics deemed triticale inferior to other grains as a feed source for livestock. However, the early triticale had greater lysine content and a better-balanced amino acid profile than other grains (Adeola et al., 1986a). Breeding programs have minimized or eliminated the likelihood of problems

associated with early triticale varieties. For example, the addition of dwarfing genes has greatly reduced lodging difficulties.

When viewed in the context of an integrated crop and livestock system, several attributes make triticale attractive. Addition of an extra crop to the typical corn-soybean rotation of the U.S. Corn Belt could reduce costs, improve distribution of labor and equipment, improve yields of corn and soybeans, provide better cash flow, and reduce weather risks. Lengthening the time between crops on the same ground can decrease the prevalence of some pests, most notably soybean cyst nematode and corn rootworm. Straw from triticale is an excellent source of livestock bedding that becomes available in the late summer when corn stalks stored from the previous fall may be in poor condition. Triticale also provides environmental benefits such as erosion control and improved nutrient recycling. If an additional crop is to be adopted by farmers, it must meet two important criteria. The crop must have a readily accessible market and be profitable to produce. Currently, there is no established market for triticale grain in Iowa. Previous work indicates triticale has potential to be grown for use as a feed ingredient in swine diets.

The United Nation's FAO (Food and Agriculture Organization) estimated over 3 million hectares of triticale grown in 2004. This figure does not include data from the United States. In 2002, there were an estimated 240,000 ha of triticale grown in the United States (Jessop, 2003). According to the FAO (2004), the leading triticale producing countries are Poland (710,000 ha), Germany (505,000 ha), Australia (346,000 ha), the former area of the USSR (331,500 ha), and France (328,000 ha). Worldwide triticale production has doubled in the last ten years. The FAO (2004) estimated 1.5 million hectares of triticale grown in 1994. In 1984, the FAO (2004) estimated only 185,000 hectares of triticale grown worldwide.

Mycotoxins and antinutritional factors in triticale

Triticale is susceptible to contamination of or possession of several antinutritional factors, including mycotoxins, ergot, protease inhibitors and tannins. While improved triticale breeding programs have greatly reduced the risk of most of these, environmental conditions that are uncontrollable may lead to possible challenges.

Triticale and all small grains can be infected with the fungus *Fusarium graminearum* (Sullivan et al., 2005). Metabolism of this fungus can produce mycotoxins. Contamination of triticale with mycotoxins will vary yearly, but is most likely to occur during cool, wet weather in early summer. Storage, insect damage, drying, harvesting, and methods of grain processing are all factors that can influence the degree of mycotoxin contamination (van Heugten, 2001). The most frequently observed mycotoxins in triticale, vomitoxin and zearalenone, are both caused by *F. graminearum*. Swine are extremely sensitive to vomitoxin, or deoxynivalenol (DON). Pigs fed diets having more than 1 ppm (part per million) DON have exhibited reduced feed intake, feed refusal, poor feed efficiency and vomiting. Zearalenone should not exceed 0.5 ppm in swine diets, as it is able to bind to estrogen receptors. Symptoms of zearalenone toxicity include hyperestrogenism (reddening and swelling of the vulva, increased uterus or mammary enlargement, and rectal and vaginal prolapse) in gilts. Zearalenone toxicity in boars includes rectal prolapse, testes atrophy and nipple enlargement (Etienne and Dourmad, 1994). Adverse health effects are possible if humans consume meat products from animals fed feeds that contained mycotoxins (van Heugten, 2001).

Ergot is a disease caused by the fungus *Claviceps purpurea*. Ergot is most common in rye, but has been observed in triticale and wheat. Ergot produces dark purple to black

sclerotia (bodies) that replace the grain in the heads. Ergot is most prevalent when moisture is available at the soil surface during spring and early summer. Grain cleaning equipment can remove sclerotia that differ in size from grain. Ergot in triticale can be managed by selection of ergot-tolerant cultivars, planting triticale in rotation with non-host crops and planting ergot-free seed. Grain containing more than 0.1% ergot sclerotia should not be fed to swine (Shimada, et al., 1974). Pigs consuming feed with levels above 0.1% ergot has resulted in reduced feed intake, feed refusal, reduced growth and poor feed efficiency (Shimada, et al., 1974; Sullivan et al., 2005). According to Sullivan et al. (2005) lameness is an early sign of ergot poisoning, while continued ergot consumption may lead to gangrene and sloughing of tissue from extremities, convulsions and staggering. If fed at extremely high levels, ergot can cause death. Shimada et al. (1974) suggested rectal prolapse might be a symptom of ergot toxicity.

The protease inhibitors most frequently found in triticale are trypsin inhibitors. Trypsin is a serine protease that when activated binds to dietary proteins to initiate hydrolysis. When protein hydrolysis is complete or excess trypsin has been activated, unbound trypsin signals a feedback inhibition to the pancreas to stop trypsin activation and secretion. However, trypsin inhibitors inhibit the action of trypsin by binding tightly to its active site, thus lowering the digestion of proteins and preventing the negative feedback signal to the pancreas (Berg et al., 2002). Without the signal to stop activation and secretion of trypsin, tissue damage can occur, leading to acute pancreatitis or hypertrophy of the pancreas (Matthews, 1999). Farell et al. (1983) suggested that trypsin inhibitory activity is species specific. In the pig, pancreatic weight is not affected by trypsin inhibitors (van Heugten, 2001). However, the interference of protein digestion and metabolism by trypsin

inhibitors reduced growth performance of pigs in several studies (Erickson et al. 1979; King, 1980; Farell et al., 1983). While trypsin inhibitor activity may be an indicator of performance of pigs, newer triticale cultivars have acceptable levels, thus their use in swine diets should not be limited by these factors.

Tannins are water soluble, polyphenolic compounds that can bind to proteins and carbohydrates (van Heugten, 2001). The effect of tannins on animal performance is variable and depends on animal species, level of tannin inclusion, length of experiment and diet composition (van Heugten, 2001). When present in diets at high levels, tannins form complexes with proteins and carbohydrates, reducing amino acid and energy digestibility and decreasing growth and efficiency of feed utilization. King (1980) determined tannin content of triticale (0.08% DM) was unlikely to be at a level sufficient to adversely affect pig performance.

Performance of pigs fed triticale

Limited research has been conducted evaluating the effects of triticale use as a grain source for swine diets. There are conflicting reports on the live performance of pigs fed triticale. Triticale has been shown to successfully replace corn, barley and wheat in swine diets without adversely affecting gain, feed intake, or gain-to-feed ratio (G:F) (Farell et al., 1983; Hale et al., 1985; Hale and Utley, 1985; Myer et al., 1986; Myer et al., 1990, Jaikaran et al., 1998). However, others have shown there may be some adverse effects on pig performance due to feeding triticale to swine (Erickson et al., 1979; King, 1980; Myer et al., 1986; Myer et al., 1989; Myer et al., 1990; Brand et al., 1995).

Myer et al. (1996) found producers are able to substantially reduce or eliminate soybean meal if supplemental lysine and threonine are added to triticale-based growing-

finishing swine diets. Growing-finishing pigs (25 to 110 kg) fed triticale-based diets with reduced soybean meal plus supplemental lysine and threonine had similar average daily gain (ADG), and gain:feed to those fed wheat-based or triticale-based diets with greater soybean meal inclusion. Growing-finishing pigs fed triticale-based diets had a similar overall ADG to those fed wheat-based or corn-based diets. Gain:feed was not affected by dietary grain source.

Work done by Myer et al. (1986) showed there was no difference in gain between nursery pigs (9 kg) fed either a corn-based diet or a 'Florida 201' triticale-based diet when the diets had an equal amount of soybean meal. However, when Florida 201 triticale diets were formulated to be equal in lysine (less soybean meal) to the corn-based diets, pigs receiving the Florida 201 triticale diet had less ADG, less feed intake, and required more feed per unit of gain than those fed the corn-based diet. Nursery pigs (9 kg) fed 'Beagle 82' triticale diets had similar ADG, average daily feed intake (ADFI), and G:F to those fed corn-based diets with or without soybean removal. These results may be due to less than predicted lysine in the triticale or possibly lower than predicted bioavailability of lysine or other amino acids. Diets were formulated on an assumed 0.40% lysine content of triticale. Analyses indicated Florida 201 had 0.36% lysine while Beagle 82 had 0.42% lysine.

When receiving either adequate (1.04%) or low (0.81%) lysine diets, nursery pigs (5.5 kg) fed diets containing corn or one of three triticale cultivars (Beagle 82, Florida 201, or 'Florico') as the grain source showed similar ADG (Myer et al., 1990). In the adequate lysine diet, ADFI was greatest for pigs receiving Florida 201 triticale, least for pigs receiving corn-based diets and ADFI of pigs receiving Beagle 82 or Florico were intermediate. Gain:feed of nursery pigs fed corn-based diets was greater than that of pigs receiving the

three triticales. Nursery pigs receiving the low lysine diets had similar feed intake and gain:feed for all treatments.

Research conducted by Jaikaran et al. (1998) showed that pigs fed one of four dietary treatments: corn-soybean meal, hulless barley-soybean meal, triticales-soybean meal, and half hulless barley and half triticales-soybean meal over three phases performed similarly. Triticales variety used in the study was 'Pronghorn'. There were no differences in ADFI between treatment groups, indicating no palatability issues associated with triticales. There were no differences in ADG between treatments in phase I (28-51 kg) and phase II (51-84 kg) and overall. However in phase III (84-110 kg), pigs receiving the hulless barley-based diets had greater ADG than those fed corn-based diets. There were no differences in G:F throughout the study.

Complete removal of soybean meal may be possible if crystalline amino acids are added to triticales-based diets fed to growing-finishing swine (Hale et al., 1985). There were no differences in ADG, feed consumed and weight gain of pigs (22 to 97 kg) fed corn-soybean meal, Beagle 82 triticales substituted for corn on an equal weight basis and Beagle 82 triticales diet formulated to be isolysinic to the corn-based diet during the overall grow-finish period. During a growing trial, there were no differences in ADG, weight gain and final weight for pigs fed diets containing either Beagle 82 triticales-soybean or Beagle 82 triticales with supplemental lysine and methionine. However, pigs fed Beagle 82 triticales plus soybean ate more feed and required 8% more feed per unit of gain than those receiving Beagle 82 triticales supplemented with lysine and methionine.

Nursery pigs (9.6 kg) fed a Beagle 82 triticales-soybean meal diet required 10% more feed per unit of gain than those fed a corn-soybean meal or a diet with equal amount of corn

and Beagle 82 triticale plus soybean meal, according to Hale and Utley (1985). However, there were no differences in ADG or ADFI. The poorer feed efficiency may have been partly due to the energy content of the triticale. The corn-soybean meal diet had 3971 kcal/kg, while the Beagle 82 triticale-soybean meal diet had 3887 kcal/kg. During a growing-finishing trial, there were no differences in weight gain, final weight, feed consumed, or G:F of pigs (22.6 kg) receiving corn-soybean meal, Beagle 82 triticale-soybean meal, Beagle 82 triticale with supplemental lysine and methionine and Beagle 82 triticale with supplemental lysine. However, pigs fed the corn-soybean meal and Beagle 82 triticale-soybean meal diets had average daily gains that were 14 and 10% more, respectively, than pigs fed Beagle 82 with only supplemental lysine (Hale and Utley, 1985). The calculated sulfur amino acid (SAA) content ($1/2$ cystine + methionine) of these diets was 0.41, 0.44, and 0.33%, respectively. The NRC (1998) SAA requirement of the growing pig (20-50 kg) is 0.54%. Pigs receiving the Beagle 82 triticale plus supplemental lysine diet were most deficient in SAA. Both supplemental lysine and methionine are necessary in the growing period if soybean meal is removed from triticale diets fed to swine. During a finishing trial, there were no differences in final weight, weight gain, ADFI, feed consumed and G:F of pigs (62.4 kg) fed corn-soybean meal or Beagle 82 triticale plus 0.195% L-lysine (Hale and Utley, 1985).

No difference in ADG or feed efficiency of nursery pigs (4 to 8 kg) fed wheat-based, 'Satu' triticale-based, or 60% wheat, 40% triticale diets (Farell et al., 1983). Growing pigs (20 to 45 kg) fed wheat-based and 67% wheat, 33% 'Groquick' triticale diets had greater ADG than those fed 67% Groquick triticale, 33% wheat or triticale-based diets. There was no difference in gain:feed. There were no differences in ADG or G:F of growing pigs fed wheat-

based, 67% wheat, 33% 'Dua' triticale, 33% wheat, 67% Dua triticale, or triticale-based diets (Farell et al., 1983).

Brand et al. (1995) observed that pigs (23 to 91kg) receiving diets that had triticale replacement of corn (33 and 67%) grew more slowly than those receiving the control (corn-soybean meal) diet. There were no differences in G:F. Growth rate decreased linearly with increased triticale inclusion. The lower growth rate may have been related to lower dry matter intake (DMI) values.

Growing-finishing pigs (26 to 98 kg) received one of five dietary treatments: corn-based, triticale-based or a mixture of the two grain sources (3:1, 1:1, or 1:3 mixes of corn and triticale), in an experiment done by Myer et al. (1989). The triticale cultivar was Beagle 82. During the grower phase, incremental addition of triticale caused a linear decrease in ADG. This decrease was not observed during the finisher phase, however over the entire grow-finish period, there was a linear decrease in ADG due to incremental triticale inclusion. There was no difference in ADFI during either phase. There was a trend for decreasing G:F during the grower phase and during the overall grow-finish period, but neither were statistically significant.

Nursery pigs (9 kg) fed Florida 201 triticale diets formulated to be isolysin to corn-based diets had less ADG and G:F than those fed the corn-based diets, according to Myer et al. (1986). Growing-finishing pigs (28 to 93 kg) fed Florida 201 triticale diets formulated to be isolysin to corn-based diets had lower ADG and G:F than those fed the corn-based diets during the finishing period. However, during the growing phase and the overall grow-finish period, there were no differences in ADG and G:F.

Myer et al. (1990) conducted a study in which nursery pigs (8 kg) were fed lysine adequate diets (1.04% lysine). Pigs receiving corn-based diets had the most ADG, pigs fed Beagle 82 triticale diets had the least ADG, and pigs fed Florida 201 or Florico triticale-based diets had intermediate growth. The same pattern was observed for ADFI i.e., pigs fed corn-based diets consumed the most feed, pigs Beagle 82 triticale ate the least and pigs fed Florida 201 or Florico triticale-based diets had intermediate feed consumption. There were no differences in G:F. When nursery pigs (8 kg) were fed low lysine diets (0.81%) by Myer et al. (1990), those receiving corn and Beagle 82 triticale-based diets had more ADG than those fed Florida 201 or Florico triticale-based diets. There were no differences in ADFI or G:F.

Nursery pigs (7 kg) receiving diets containing 0, 20, 40 or 60% triticale had more ADG than pigs receiving 80 or 100% triticale diets. Based on regression analysis, optimum growth performance by replacement of corn with triticale was found to be 24% (Erickson et al., 1979). Palatability or trypsin inhibitor activity may have affected feed intake and protein utilization when triticale was fed at the 80 and 100% level. Pigs (10 kg) fed corn-soybean meal and 50% triticale diets had more ADG than those fed 100% triticale diets. Pigs receiving the 100% triticale diet required 21 and 22% more feed per unit of gain than those receiving the corn-soybean meal and 50% triticale diets, respectively. Pigs (21 kg) fed corn-soybean meal and 50/50 mixture of corn and triticale plus soybean meal had more ADG than pigs fed a 50/50 mixture of corn and triticale with reduced soybean meal plus lysine. Because lysine was added to the 50/50 mixture of corn and triticale, threonine would most likely be limiting, resulting in adverse gains. The 50/50 diet plus lysine resulted in more ADG than the 100% triticale diet.

Growth rate of pigs (20-70 kg) was not affected by up to 67% replacement of wheat with triticale. However, when triticale completely replaced wheat, growth rate and feed conversion were reduced. The substitution of wheat with triticale had no effect on feed intake (King, 1980).

There are conflicting results on the effects triticale-based diets have on pig performance. Studies have shown triticale may successfully replace corn, barley and wheat in swine diets without adversely affecting gain, feed intake, or gain-to-feed ratio (Farell et al., 1983; Hale et al., 1985; Hale and Utley, 1985; Myer et al., 1986; Myer et al., 1990, Jaikaran et al., 1998). However, others have shown there may be some adverse effects on pig performance due to feeding triticale to swine (Erickson et al., 1979; King, 1980; Myer et al., 1986; Myer et al., 1989; Myer et al., 1990; Brand et al., 1995).

Carcass characteristics of pigs fed triticale

There are several reports of pigs fed triticale-based diets having similar carcass measurements to pigs fed wheat-based, barley-based, and corn-based diets (King, 1980; Farell et al., 1983; Hale and Utley, 1985; Brand et al., 1995; Myer et al., 1996; Jaikaran et al., 1998). Myer et al. (1996) found that backfat thickness, loin muscle area (LMA), and percentage carcass lean of pigs did not differ if fed triticale-based, wheat-based, or triticale plus supplemental lysine diets. Pigs fed triticale-based diets also had similar percentage carcass lean to those fed wheat-based or corn-based diets (Myer et al., 1996). Brand et al. (1995) observed no differences in dressing percentage, LMA, or backfat thickness for pigs fed up to 67% replacement of corn with triticale.

Work done by Jaikaran et al. (1998) concluded that dressing percentage was highest for pigs receiving corn-based diets, lowest for pigs fed half hulless barley, half triticale diets,

with pigs receiving triticale-based and hulless barley-based diets having intermediate dressing percentage. Backfat thickness was most in pigs receiving half hulless barley, half triticale treatment (20.7 mm), a value different from the hulless barley and triticale fed pigs (17.5 and 17.9 mm, respectively), but not from the corn fed pigs (19.7 mm). The most lean percentage observed was from triticale fed pigs (56.9%), which was more than hulless barley/ triticale fed pigs (55.0%). Pigs fed hulless barley-based and corn-based diets were intermediate with 56.6 and 55.6% lean yield, respectively.

No differences were found in carcass length, backfat, loin eye area (LEA), or percent lean cuts (weight of trimmed shoulders, loins, and hams as a percentage of slaughter weight) for pigs receiving diets consisting of corn-soybean meal, Beagle 82 triticale-soybean meal, Beagle 82 triticale with supplemental lysine and methionine and Beagle 82 triticale with supplemental lysine, according to Hale et al. (1985). There were no differences observed in carcass length, backfat, LEA or percentage lean cuts for finishing pigs fed corn-soybean meal or Beagle 82 triticale plus 0.195% lysine diets. Backfat thickness was similar when triticale completely replaces wheat in growing-finishing pigs diets (King, 1980; Farell et al., 1983). King (1980) also observed no differences in percent lean of ham meat.

There has been limited research conducted evaluating the effects triticale-based diets have on pig carcass characteristics. However, pigs fed triticale have similar carcass measurements to those fed wheat, barley and corn (King, 1980; Farell et al., 1983; Hale and Utley, 1985; Brand et al., 1995; Myer et al., 1996; Jaikaran et al., 1998).

Meat quality and palatability of pork from pigs fed triticale

Triticale can be substituted for corn or barley in swine diets without compromising meat quality or palatability (Robertson et al., 1999). Robertson et al. (1999) found no

differences in protein or intramuscular fat content of loin muscle of pigs fed corn-based, hulless barley-based, 50/50 mixture of hulless barley and triticale, and triticale-based diets. Loin muscle color was darker in pigs fed corn than those fed hulless barley or triticale. Water holding capacity (WHC) of loin eye muscle was lower in pigs fed barley than that of pigs fed other three diets, but all were in the normal range. A taste panel found chops from pigs fed barley-based diets more tender than chops from pigs fed corn-based or the 50/50 mixture of hulless barley and triticale diets. Chops from pigs fed triticale-based diets were similar to those from other three treatments.

Feed is the most important environmental factor affecting meat flavor. Any feed that influences the concentration of the flavor precursors or deposits unique components in the fat will affect the cooked meat flavor. Feeding unsaturated fats to pigs increases the unsaturation of pork, but results in only minor changes in pork flavor. According to Melton (1990), triticale replacement of corn up to 80% had no effect on pork flavor desirability. Feeding triticale increased the percentages of palmitoleic (16:1) and linoleic (18:2) acids, but decreased the percentages of palmitic (16:0) and stearic (18:0) acids in backfat and longissimus muscle.

Triticale may be fed to pigs without compromising meat quality or pork palatability. Pork from triticale fed pigs has similar intramuscular fat content, water holding capacity, color and eating desirability to pork from pigs fed corn or barley (Robertson et al., 1999). Melton (1990) found pigs fed triticale-based diets increased unsaturated fatty acids and decreased saturated fatty acids in the loin and fat when replacing corn as the dietary grain source.

Nutritive Value of Triticale

Protein and amino acid content

Triticale has more crude protein and a better, or more balanced, amino acid profile than corn (Adeola et al., 1986a). Feedstuffs with a high quality protein (an amino acid profile that more closely matches the needs of the pig) can lower the level of dietary protein fed. This will therefore decrease nitrogen excretion by the pig (NRC, 1998). The first-limiting or most-limiting amino acid in swine diets is usually lysine (Myer and Barnett, 1985). Because triticale has greater lysine content than corn (30 to over 50% more), (Hale et al., 1985; Myer and Barnett, 1985; Adeola et al., 1986a,b; Myer et al., 1986; Myer et al., 1989; Myer et al., 1990; Myer et al., 1996; Jaikaran et al., 1998; NRC, 1998) it has potential as a valuable ingredient for swine diet formulation. Producers that use triticale may be able to decrease the amount of soybean meal in growing-finishing pig diets by five percentage points, thereby reducing the cost of the diet.

NRC (1998) values of protein and lysine content of triticale are 12.5 and 0.39%, respectively, compared to 8.3 and 0.29% for corn, respectively. King (1980) found triticale contained 11.4% crude protein and 0.44% lysine. According to Myer and Barnett (1985) triticale has more protein and essential amino acids than corn, having nearly double the lysine content (0.40 vs. 0.24%). According to Hale et al. (1985), lysine content of Beagle 82 triticale was 78% more than corn (0.48 vs. 0.27%). Crude protein was 45% more in Beagle 82 triticale than corn (14.6 vs. 10.1%). In a study by Myer et al. (1986), Florida 201 triticale had 52% more lysine than corn (0.44 vs. 0.29%), but less than Beagle 82 triticale (0.47%). Work by Myer et al. (1989) found that Beagle 82 on average, contained 53% more protein (13.0 vs. 8.5%) and 68% more lysine (0.42 vs. 0.25%) than corn. Average lysine content of

Beagle 82 triticale, Florida 201 triticale, Florico triticale and corn was 0.48, 0.43, 0.41 and 0.29%, respectively, in a study by Myer et al. (1990). Myer et al. (1996) found triticale averaged 33% more crude protein (11 vs. 8.3%) and 50% more lysine (0.39 vs. 0.26%) than corn. Protein content in triticale was similar to that of soft red winter wheat. Lysine and threonine proportions were more in triticale than in wheat. Other amino acid contents were similar. Jaikaran et al. (1998) determined the lysine content of hullless barley, corn, and Pronghorn triticale was 0.47, 0.37 and 0.36%, respectively.

There are several factors that may influence the crude protein and amino acid content of triticale. Myer et al., (1996) stated that greater than normal rainfall during early growing periods may cause below normal protein and amino acid contents. Newer cultivars of triticale have plumper grain of heavier test weight and greater yields. Newer triticales are also greater in starch content. Selecting for these traits has lowered the protein content of triticale (Myer et al., 1996; Jaikaran et al., 1998). Protein and lysine content may vary by triticale variety, location grown and year grown (Rundgren, 1988; Myer et al., 1989; Jaikaran et al., 1998;). Jaikaran et al. (1998) also found that cleaning triticale may reduce protein content, as the larger, plumper kernels have less protein than the smaller ones. During the cleaning process, smaller kernels may be blown away, thereby decreasing the protein content. Adeola et al. (1986b) noted that level of nitrogen application and time of nitrogen application may affect protein content of triticale. Because there appears to be a large variation in crude protein and lysine content of triticale, it is recommended that triticale be tested for nutrient composition if it is to be included as an ingredient in swine diets.

There may be a negative correlation between crude protein content of triticale and lysine content (Farell et al., 1983; Rundgren, 1988). Farell et al. (1983) found crude protein

content of triticale samples ranged from 8.3 to 17.2%. Lysine content ranged from 0.33 to 0.52%. There was a negative correlation between lysine content of protein and crude protein content ($r = -0.70$). Threonine content ranged from 0.30 to 0.59%. Crude protein ranged from 9.4 to 18.5% for five cultivars grown over three growing seasons, in work done by Rundgren (1988). At equal crude protein contents, different cultivars had substantially different lysine content. There was a negative correlation between lysine and crude protein content of triticale. However, there was a positive correlation between glutamic acid and crude protein content of triticale. Adeola et al. (1986a,b) however, found that lysine increased when crude protein increased.

Triticale has more crude protein and lysine and an amino acid profile that more closely matches the nutrient needs of pigs than corn. This may be advantageous, as producers are able to decrease the amount of supplemental protein or amino acids in swine diets, thereby reducing the cost of the diet. It appears as the amount of crude protein increases in triticale, the amount of lysine decreases. Several factors may influence the crude protein and amino acid contents of triticale. Large amounts of rain during early growing periods may decrease the protein and amino acid contents. Year and location grown may influence these traits. Selecting triticale cultivars for greater starch content has decreased protein content.

Protein and amino acid digestibility

Protein and amino acid digestibilities determined at the end of the small intestine (ileal digestibilities) are more useful than fecal digestibilities determined over the entire digestive tract. This is because values determined by fecal methods are affected by microbial degradation of amino acid in the large intestine to ammonia or amines, which are readily excreted in the urine and are of little nutritive value to the pig (Adeola et al., 1986a,b;

Haydon and Hobbs, 1991; van Barneveld and Cooper, 2002). In this discussion, apparent ileal digestibility is a measure of a dietary amino acid or protein that has disappeared from the gut when digesta reach the terminal ileum. The formula used to calculate apparent ileal digestibility is: $\text{Apparent digestibility (\%)} = ((\text{Nutrient intake} - \text{Nutrient in digesta}) / (\text{Nutrient intake})) \times 100$. True digestibility is a measure that has corrected for endogenous amino acid or protein losses. Endogenous amino acids are derived from proteins secreted into the digestive tract. The formula used to calculate true ileal digestibility is: $\text{True digestibility (\%)} = ((\text{Nutrient intake} - (\text{Nutrient in digesta} - \text{Endogenous nutrient})) / (\text{Nutrient intake})) \times 100$. To measure endogenous amino acid losses, animals are typically fed a protein-free diet. True digestibility values are greater than apparent digestibility values.

There have been conflicting results regarding protein digestibility of triticale. According to Erickson et al. (1979), apparent fecal protein digestibility tended to increase with increasing triticale inclusion. Myer et al. (1989) found that crude protein digestibility increased linearly with the addition of triticale to diets, for grower and finisher periods. This was observed for two years' crops of triticale. Apparent crude protein digestibility was similar for diets containing Florida 201 triticale and corn fed during the grower stage in a study by Myer et al. (1986). Other studies have shown both reduced protein digestibility when triticale replaced corn as the grain source (Erickson et al., 1978; Adeola et al., 1986b) and similar protein digestibility (Farell 1983, Adeola et al., 1986a). When comparing true digestibility of nitrogen for triticale, wheat and rye, Rundgren, (1988) concluded triticale and wheat were equal and greater than rye. Haydon and Hobbs (1991) determined the nutrient digestibility of soft winter wheat, Beagle 82 triticale, Florico triticale, and pearl millet

measured near the end of the small intestine and over the entire digestive tract in finishing pigs. Ileal nitrogen (N) digestibility was similar for all four diets.

According to NRC (1998), true ileal digestibility of most amino acids is greater in corn than triticale. The exceptions are lysine, cystine and tryptophan. In terms of apparent ileal digestibility of amino acids, only leucine, methionine and tyrosine have greater digestibilities in corn than triticale. Low protein feedstuffs have undervalued apparent ileal amino acid digestibilities relative to high protein feedstuffs because of the relative greater contribution of endogenous amino acids (NRC, 1998). According to Haydon and Hobbs (1991), ileal lysine digestibility was similar between soft winter wheat, Beagle 82 triticale, Florico triticale, and pearl millet and averaged 74.1%. Fecal digestibility of amino acids was similar in wheat and the triticale varieties. The one exception was fecal lysine digestibility, which was greatest in wheat, least in pearl millet, and intermediate in Beagle 82 and Florico triticale. Individual fecal amino acids were generally less for pearl millet than wheat or triticale. Apparent amino acid digestibilities were similar between soft winter wheat and the Beagle 82 and Florico triticale varieties. Van Barneveld (1998) found the ileal digestibility of amino acids in triticale is similar to that measured in wheat and sorghum and is superior to that of barley.

Adeola et al. (1986a) compared the amino acid digestibility of two samples of OAC Wintri triticale with differing crude protein contents to that of corn. Triticale A had 15.5% crude protein. Triticale B had 10% crude protein. Triticale A had greater levels of proline and glutamic acid than triticale B. Lysine content was 0.33, 0.56 and 0.45 for corn, triticale A and triticale B, respectively. Corn had greater apparent digestibilities of essential amino acids except methionine, isoleucine and valine than either triticale. Triticale B had lesser

digestibilities of essential amino acids except arginine and threonine than triticale A. Lysine and threonine were the least available amino acids in triticale. The distribution of amino acids in the grain kernel may explain the variations in availability or digestibility. Amino acids that have low availability (lysine, for example) have a high prevalence in the aleurone layer of the kernel, which is much less accessible than the endosperm. The endosperm has a high proportion of more available amino acids, such as glutamic acid. However, threonine, which has a low availability, is found in both regions. Digestibility of most amino acids was higher in corn than triticale. Except valine, lysine and isoleucine, digestibilities based on fecal analysis were greater in corn than triticale. Lysine and threonine were the least available amino acids in triticale and corn, based on fecal analysis.

There are inconsistent results when evaluating the protein and amino acid digestibilities of triticale. Some studies have shown protein digestibility increases as triticale replacement of corn increases (Erickson et al., 1979; Meyer et al., 1989). According to Meyer et al. (1986), corn and triticale have similar protein digestibility. Others have shown protein digestibility decreases when triticale replaces corn as the grain source in swine diets (Erickson et al., 1978; Adeola et al., 1986b). The protein digestibility of triticale and wheat appear to be similar (Rundgren, 1988; Haydon and Hobbs, 1991). According to NRC (1998), the true ileal digestibility of most amino acids in corn is greater than triticale. Van Barneveld (1998) found apparent amino acid digestibilities were similar between wheat, triticale and sorghum. Adeola et al. (1986a) found the digestibilities of most amino acids are greater in corn than triticale. According to Adeola et al. (1986a), triticale with greater crude protein has greater digestibilities of essential amino acids than triticale with less crude protein.

Nitrogen balance

Haydon and Hobbs (1991) found no difference between soft winter wheat, Beagle 82 triticale, Florico triticale, and pearl millet in N retention, expressed as a percentage of intake or of absorbed N. Hale et al. (1985) determined in a nitrogen balance study that nitrogen balance was similar for all three treatments (corn-soybean meal, Beagle 82 triticale with equal soybean meal to corn diet and Beagle 82 with reduced soybean meal). However, pigs fed both diets with Beagle 82 triticale consumed more nitrogen and excreted more nitrogen in urine than pigs fed the corn-soybean meal diet. Pigs fed corn-soybean meal retained more N as a % of N consumed than those fed Beagle 82 triticale with 30% less soybean meal. The difference was significant, but small enough to likely not affect performance. According to Erickson et al. (1979), as triticale inclusion increased, N intake and N retention increased, except at the 80% triticale level, which had a decreased N retention.

Biological value and net protein utilization

Rundgren (1988) determined the biological value (BV) and net protein utilization (NPU) was greatest for rye, least for wheat and intermediate for triticale. As crude protein in triticale increased, BV decreased. Adeola et al., (1986b) found no differences in BV and NPU between triticale and corn. BV is a measure of the relationship of protein (or N) retention to protein (or N) absorption. NPU measures efficiency of growth by comparing body N content resulting from feed a test protein with that resulting from feeding a comparable group of animals a protein-free diet for the same length of time.

Energy content

According to the NRC (1998), triticale has less digestible energy (3320 vs. 3525 kcal/kg DE) and metabolizable energy (3180 vs. 3420 kcal/kg ME) than corn, but more net

energy (2420 vs. 2395 kcal/kg NE). Pigs are able to compensate for lower energy diets by consuming more feed. If fed *ad libitum*, feed intake of growing-finishing pigs is controlled by the energy density of the diet (NRC, 1998).

King (1980) found the gross energy (GE) and DE of triticales to be 4517 kcal/kg DM and 3871 kcal/kg DM, respectively. DE content for pigs of two samples of triticales was 3824 kcal/kg, according to Farrell et al. (1983). Rundgren (1998) determined the DE content of wheat was more than that of triticales. The average DE content of rye (3537 kcal/kg) was less than that of triticales (3632 kcal/kg) and wheat (3680 kcal/kg). The same pattern followed for ME content. The average ME content of rye, triticales and wheat was 3561 kcal/kg, 3609 kcal/kg and 3633 kcal/kg, respectively. Van Barneveld (2001) found that three triticales varieties (Abacus, Credit and Tahara) had greater DE content than barley. Tahara had more DE than Abacus and Credit. According to Haydon and Hobbs (1991), wheat and pearl millet had greater DE and ME contents than Beagle 82 triticales. Florico triticales was intermediate in DE, but had a greater ME concentration than Beagle 82 triticales. ME concentration was lower for the triticales, however. Adeola et al. (1986b) found digestible and metabolizable energy values were greater for corn than triticales. DE values were 3560 kcal/kg, 3770 kcal/kg and 4080 kcal/kg for low crude protein triticales, high crude protein triticales and corn, respectively. The values were all different. ME was greater in corn (3660 kcal/kg) than the triticales, which had similar values (3190 and 3120 kcal/kg) for the high and low crude protein triticales, respectively.

Triticales has less energy than corn. However, pigs are able to compensate for less dietary energy because feed intake of growing-finishing pigs fed *ad libitum* is controlled by

the energy density of the diet (NRC, 1998). Pigs fed less energy dense diets will generally consume more feed than those fed diets with greater energy densities.

Energy and dry matter digestibility

Energy and dry matter digestibility may be related to the ash, crude fiber and starch contents of a feedstuff. Year-to-year variations in energy and dry matter digestibility of a feedstuff are possible. Studies have shown triticale has less energy and dry matter digestibilities than soft winter wheat, pearl millet and corn (Haydon and Hobbs, 1991; Hale et al., 1985; Adeola et al., 1986b). However, Myer et al. (1986) found dry matter digestibilities of corn and triticale were similar.

According to Haydon and Hobbs (1991), energy and dry matter (DM) digestibilities were less for Beagle 82 triticale than for soft winter wheat and pearl millet. Florico triticale was intermediate in energy digestibility, but had a greater DM digestibility than Beagle 82 triticale. The reduced energy and DM digestibilities of Beagle 82 may have been due to its ash (2.02%) and crude fiber (3.24%) contents, which were more than wheat (1.08 and 2.02%), pearl millet (0.47 and 2.06%) and Florico triticale (1.48 and 2.74%). Energy digestibility measured over the entire tract was more for wheat than for the other grains. This may be due to the starch content of wheat being more than that of pearl miller and triticale. Wheat's DM digestibility was more than the Beagle 82 triticale; Florico triticale and pearl millet had intermediate DM digestibilities.

Myer et al. (1989) found a slight difference in DM digestibility for increased triticale added to swine diets for one year's crop, but not another's, which may suggest possible year-to-year differences in the feeding value of triticale. DM digestibilities were similar for diets containing Florida 201 triticale and corn fed during the grower stage (Myer et al., 1986).

Digestibility coefficients of DM for pigs fed corn-soybean meal and Beagle 82 with similar amount of soybean meal were more than for pigs receiving Beagle 82 with 30% less soybean meal, according to Hale et al. (1985). This may be due to dehulled soybean meal being more digestible than the cereal grains. Digestibility coefficients for gross energy (GE) and crude protein were similar for all three diets.

Adeola et al. (1986b) compared the protein and energy value of OAC Wintri triticales and corn for pigs. The dry matter digestibility was more in corn than both triticales (high and low crude protein). DM and GE digestibilities and DE were more in the high crude protein triticales than the low crude protein triticales.

Phosphorus

Phosphorus is a mineral that plays a major role in the development and maintenance of the skeletal system and performance of many other physiological functions. While corn and triticales have similar concentrations of phosphorus, (0.28 and 0.33%, respectively) only 14% of the phosphorus in corn is available, whereas 46% of the phosphorus in triticales is available (NRC, 1998). The phosphorus in corn is bound as phytic acid and is poorly available. The higher availability of phosphorus in triticales (and wheat) is due to the presence of a naturally occurring phytase enzyme, which releases some of the bound phosphorus. Replacing corn with triticales in swine diets will reduce the amount of supplemental inorganic phosphorus needed, reducing dietary costs. Feeding triticales to swine instead of corn may also reduce the amount of phosphorus excreted up to 30% (Sullivan et al., 2005). This has great environmental implications, as excess phosphorus application from swine manure results in phosphorus buildup in soil. Continued application of phosphorus to land already high in phosphorus will cause eroding of phosphorus into lake and streams, leading to growth

of algae and a worsening of water quality. There is mounting evidence that suggests phosphorus will replace nitrogen as the nutrient that limits land application of manure in areas of intensive swine production.

Bedded hoop barns

Introduction

Alternative swine production systems have become increasingly popular among pork producers and consumers. Consumers may have a negative perception about current, conventional swine production systems. Producers are attracted to alternative production systems for many reasons. Niche market access, animal welfare concerns, low-capital investments, versatility, health concerns of the producer, and environmental considerations are all possible reasons for utilizing alternative swine production systems.

One alternative swine production system that has become prevalent is hoop barns. Hoop barns are also known as hoop structures or simply hoops. A hoop is a Quonset-shaped structure resembling a large tent. Hoops have concrete or wood sides that are used as sidewalls. Sidewalls range from 1.2 to 1.8 m high (Conner et al., 1993; Gadd, 1993; Brumm et al., 2004). Steel arches are attached to the tops of the sidewall posts, forming the metal framework of the roof. To assist in stability and alignment, steel purlins are attached to the arches and run the length of the building. Polyethylene fabric, which is resistant to ultraviolet radiation and leakage, covers the metal framework. The fabric cover is securely fastened to the metal framework and base of the building by laced rope or ratchets. Hoops used for feeding growing-finishing pigs typically have a large, deep-bedded area for sleeping and dunging and a concrete pad on the end of the building for feeders and waterers. The floor can be dirt or concrete. Cornstalks or straw in large bales are usually used as the bedding source

covering the floor (Honeyman et al., 1999; Brumm et al., 2004). However, wood shavings or other absorbent organic material may be used (Honeyman et al., 2001a). Bedding is added at the discretion of the producer to absorb urine and feces, and is added in quantities to maintain a relatively dry bedding pack. Bedding is also important for temperature regulation by the pig (burrowing to reduce skin exposure and reducing heat loss during winter) and allowing natural behavior, which may reduce aggressive encounters with pen mates. In the Midwest, the north end of the hoops is usually closed except for a small opening at the top during winter, while the south end is left open. This allows for sufficient air circulation to prevent condensation on the underside of the tarp (Honeyman and Harmon, 2003). During the rest of the year, both ends are open (Honeyman et al., 2001a). In this discussion, hoops and outdoor rearing systems are considered analogous because the hoop barns modify the outdoor thermal environment only slightly.

History of hoop barns

While hoops were initially developed in Canada, the concept of hoop structures was generally based on a revived interest in outdoor pig production in Europe (Andersson and Botermans, 1993; Arey, 1993; Jensen et al., 1993; Thornton, 1993;) and more specifically on the tunnel housing system in Japan (Gadd, 1993). In 1982, swine producers in Japan adopted the use of the covered tunnel, a half-moon shaped structure with metal rods that are anchored into the soil (Gadd, 1993). The outer cover was silver colored, while the inside of the tarp was colored black to help with temperature regulation. The tunnel had a concrete area with waterers and feeders, while the remaining area was an earthen floor covered with sawdust or wood shavings. The Japanese mastered the use of a polyvinyl-covered tunnel with shallow

sawdust bedding for feeding swine. Each tunnel would hold 50 to 70 market pigs (Gadd, 1993).

The concept of tent-like structures for housing swine was transferred to Manitoba, Canada circa 1990, where they were named “BioTech shelters.” Work by Conner (1993, 1994) showed these shelters worked well for growing-finishing swine. Hoop structures were introduced to the United States in the mid-1990s and were rapidly adopted. According to Honeyman et al., (2001b), there were more than 2000 hoop barns built in Iowa by 760 producers. About 90% of the hoops are used for finishing swine. Typical hoops (10 x 30 m) hold about 200 pigs (Honeyman et al., 2001a).

Advantages of hoop barns

Hoops have the advantage of being a versatile, low initial cost, simple housing system, compared to a confinement building. The initial cost of hoops for finishing pigs is about \$50-60/pig space, or roughly one-third that of the initial pig space cost of a confinement building (Honeyman et al., 2001a). This affords pork producers the advantage of leaving the market quickly, if needed, without a large investment (Brumm et al., 2004). The hoop structures can be erected rapidly, often with on-farm labor, are simple to maintain with little major mechanical needs and do not require electricity, as they use natural ventilation. Hoops are also versatile, as they can be used for other agricultural needs such as storing machinery, large round bales, or grain. Pigs raised in hoops may have a market advantage, as many pork niche markets require animals to have outdoor access. Animal welfare is better in hoops than confinements (Lay et al., 2000). Pigs finished on bedding have fewer foot and toe lesions (Gentry et al., 2002a) and overall injuries (Lay et al., 2000) than those on concrete slats or in non-bedded confinement.

There may also be advantages to bedded hoop barns in terms of public perception. Ngapo et al. (2003) reported that consumers believed that intensive swine production systems (confinements) were comparable to intensive poultry confinement buildings, factories and prisons. Consumers in the study thought pigs raised outdoors were happier than pigs raised indoors. According to Korsching et al. (2004), when rural residents and farmers were asked what they viewed as acceptable and unacceptable rural development activity, confinement hog lot development ranked below development of prisons, solid waste landfills, slaughter plants, and sewage treatment plants.

Hoops are environmentally advantageous, because most of the liquid manure problems of confinement waste (leaks, spills and odor) are minimized because hoops have solid manure. Air quality is good for both pigs and producers due to the natural ventilation. Also, work is currently underway at the Iowa State University Armstrong Research Farm; Lewis, IA, to determine the feasibility of using hoops for finishing beef cattle.

Disadvantages of hoop barns

Because pigs raised in hoops are in one large group, management requirements differ from confinement-raised pigs. Keen animal observation skills in hoops are needed (Honeyman et al., 2001a). Another disadvantage of hoops or other outdoor production systems is disease control (Lay et al., 2000). Disease challenges can come from the soil underneath the bedding pack or from wildlife, as biosecurity is more difficult in hoops than confinements. Large quantities of bedding are needed when finishing pigs in hoops, which increases labor requirement and variable costs of production. Pigs raised in hoops or other alternative production systems may have poorer feed efficiency, particularly in the winter (Conner, 1993; Conner, 1994; Honeyman and Harmon, 2003; Gentry et al., 2004). Pigs

raised in hoops will likely consume some amount of bedding, increasing their fiber consumption and fecal excretion (Huenke and Honeyman, 2001). Increased fiber consumption may inhibit growth. Fiber increases digesta rate of passage, thereby decreasing absorption and nutrient utilization by the pig.

Performance of pigs raised in hoop barns

Several studies have shown that while confinement housing and hoop barn or outdoor housing are strikingly different swine production systems, overall pig performance and carcass characteristics differ slightly. Because hoop barns do not provide the thermoregulation capabilities of confinements, seasonal trends are possible. During the summer, ADG of finishing pigs in hoop barns or other outdoor production systems may be greater than ADG of pigs in confinement (Conner, 1993, 1994; Gentry et al., 2002a,b; Honeyman and Harmon, 2003;). However, during the winter, ADG of finishing pigs may be similar in hoops or confinement (Conner, 1993, 1994; Gentry et al., 2002a; Honeyman and Harmon, 2003). When season is not considered, ADG of pigs on bedding may be greater than pigs without bedding (Morgan et al., 1998).

Pigs reared in hoops or outdoors consume more feed during the winter than pigs reared in conventional housing systems (Conner, 1993, 1994; Honeyman and Harmon, 2003; Gentry et al., 2004). This is likely due to the increased energy requirement of the pig to maintain body temperature. During the summer, ADFI of pigs reared in alternative housing systems and conventional housing systems is similar (Conner, 1993, 1994; Gentry et al., 2002b; Honeyman and Harmon, 2003). Morgan et al. (1998) found no difference in feed intake for pigs housed on bedding or barren pens.

Pigs raised in hoop barns or other enriched (bedded) systems usually have lower G:F during the cold months than pigs raised indoors (Honeyman and Harmon, 2003; Gentry et al., 2004). Again, this is likely due to the increased energy requirement of the pig to regulate body temperature. Less net energy is available for growth. During the summer, G:F of pigs in hoops may be similar to G:F of pigs in confinement buildings (Honeyman and Harmon, 2003). When comparing feeding finishing pigs on alfalfa pasture to concrete slats, Gentry et al. (2002b) found lower G:F of pigs on alfalfa pasture. There may be other contributing factors, including more area to move, thereby expending more energy for movement and less energy used for growth. Morgan et al., (1998) found no difference in G:F of pigs reared with or without straw bedding.

Carcass characteristics of pigs in hoops

Few studies have been conducted comparing the carcass characteristics of pigs raised in hoop barns or other enriched environments to the conventional, concrete-slatted floor confinement building. Honeyman and Harmon (2003) found hoop pigs had more backfat than confinement pigs. Gentry et al. (2002b) found outdoor pigs had more last rib backfat, but similar first rib backfat to pigs raised indoors. Pigs raised on alfalfa had similar backfat thickness to pigs raised on concrete (Gentry et al., 2004) and more backfat in another study (Gentry et al., 2002a). Klont et al. (2001) found no difference in backfat for pigs raised on bedding or concrete.

There appears to be discrepancies in loin muscle area trends of pigs raised in hoops or other alternative systems. Honeyman and Harmon (2003) found pigs in hoops had smaller LMA than pigs finished in confinement. According to Gentry et al. (2004), and Gentry et al.

(2002b), LMA of pigs raised in conventional or outdoor systems is similar. Finally, Gentry et al. (2002a) found pigs raised outdoors had larger loin muscle areas than pigs raised indoors.

Work by Honeyman and Harmon (2003) showed pigs finished in hoops had less calculated lean weight, less carcass lean and lower yield than pigs finished in confinement. However, Gentry et al. (2004) found heavier hot carcass weight and no difference in carcass length, ham muscle score or percentage of four lean cuts between pigs raised in conventional or outdoor systems. Hot carcass weight of pigs raised outdoors was heavier than that of pigs raised indoors, according to Gentry et al. (2002a) Hot carcass weight of pigs raised outdoors and indoors was similar, in a study by Gentry et al. (2002b). When comparing bedded to concrete housing systems, Klont et al. (2001) found no difference in carcass weight and meat percentage of pigs.

Meat quality and palatability of pork from pigs raised outdoors

Pork from pigs finished on deep bedding may have an advantage in pork quality (Gentry et al., 1999; Gentry et al., 2002b; Lambooij et al., 2004). Loin chops from pigs finished outdoors may have a lesser shear force value (a measure of meat tenderness) than loin chops from pigs finished indoors (Gentry, 1999; Gentry 2002b). However, other studies have shown no difference in shear force of loin chops from pigs raised outdoors and indoors (Gentry et al., 2002b; Gentry et al., 2004).

Klont et al. (2001) found pigs reared in bedded systems had a greater 24-hour postmortem pH than those reared on slats. This resulted in pigs in confinement having a greater percentage of drip loss or purge than pigs on bedding. Lambooij et al. (2004) attributed greater water holding capacity of pigs raised on bedding to their ability to cope with stress better than pigs raised in confinement. Because stocking densities are usually

lower in bedded systems, pigs can move about freely, becoming more resistant to exhaustion. Pigs in bedded systems may have a slower glycolytic rate than pigs in conventional systems, thereby improving water-holding capacity. Other experiments have shown no difference in muscle pH and water-holding capacity or purge loss due to housing system (Gentry et al., 2002b; Gentry et al., 2004).

Pork from pigs outdoors has been shown to be redder (higher Minolta a*) than pork from pigs indoors with no difference in lightness (Minolta a*) or yellowness (Minolta b*) of color (Gentry et al., 2004). However, Gentry et al. (2002b) found pork from pigs raised outdoors had a greater Minolta L* score, indicating lighter meat.

There is difference between housing system in terms of percent fat, percent moisture or percent protein in pork (Gentry et al., 1999; Gentry et al., 2002b). Marbling scores of pork from pigs raised outdoors has been shown to be less than pigs reared in confinement (Gentry et al., 2002a) and similar (Gentry et al., 2002b).

Little work has been previously reported on the effects of raising pigs indoors versus outdoors in terms of sensory evaluation of pork. According to Gentry et al. (1999), a taste panel found pork from pigs raised on deep-bedding to have greater scores for tenderness, juiciness, flavor intensity and overall mouthfeel, compared to pork from pigs raised in conventional systems. However, other studies have shown no difference in sensory evaluation of pork with respect to housing system used to raise market pigs (Gentry et al., 2002a,b; Gentry et al., 2004). Though loin chops from bedded pigs in the study by Gentry et al. (2002b) were found to have lesser shear force values, this did not correlate with a difference in tenderness reported by sensory evaluation. Gentry et al. (2002a) found that loin chops from pigs raised outdoors during the summer deteriorated (more discoloration and

browning) more quickly in a retail display study than chops from pigs raised indoors. There was no difference in deterioration of chops from pigs raised in the different housing systems during the winter. More work needs to be done on meat quality of pigs reared in alternative systems.

Temperature fluctuations in hoops and other alternative swine production systems may have an effect on pork quality attributes. Temperature affects fat deposition and fatty acid profiles. Fatty acids affect fat firmness, shelf life and pork flavor. As the level of unsaturation in pork fat increases, the fat becomes less firm (Wood et al., 2004). According to the National Pork Producers Council (NPPC, 1999), soft fat is a major issue related to pork fat quality. Soft fat causes problems in cutting, grinding and slicing during carcass processing. Unsaturated fats are susceptible to lipid oxidation leading to rancidity, therefore decreasing pork shelf life. Increased levels of unsaturated fatty acids negatively affect pork flavor during sensory evaluation.

Bee et al. (2004) found that pigs finished outdoors at 5°C had decreased levels of monounsaturated fatty acids (MUFA), increased levels of polyunsaturated fatty acids (PUFA) and similar saturated fatty acids (SFA) in the intramuscular lipid compared to pigs finished indoors at 22°C. Total intramuscular lipid content was lower in pigs reared outdoors. Pigs finished outdoors at the lower temperature had higher concentrations of both MUFA and PUFA and lower proportion of SFA in their backfat compared to pigs finished indoors at the higher temperature. Rinaldo and Mourot (2004) studied the effects of high temperatures on fat characteristics of pigs. Pigs finished at 20°C had more backfat than pigs finished at 24.8°C and 27.9°C. Pigs reared at higher temperatures (24.8°C) had lower concentrations of MUFA and higher concentrations of PUFA in backfat.

Behavior of pigs in enriched systems

The roof of an enriched swine housing system is not insulated, thus the temperature inside is dependent on the temperature outside. Pigs are sensitive to slight environmental changes because they have a very thin coat of hair and lack the ability to sweat. Pigs respond to environmental changes by altering their feed intake and behavior (Pedersen et al., 2003). When temperatures are extremely cold, pigs will have poor feed efficiency, as they have a greater energy need for thermoregulation. Conversely, when temperatures are extremely high, the appetite of the pig will diminish. According to Larson et al. (2003), as pigs grow, their ability to tolerate high temperatures decreases, but their ability to tolerate cold temperatures increases. As outdoor temperature decreases, huddling and selecting warm environments (heat conserving behavior) by pigs increase (Larson et al., 2003; Pedersen et al., 2003). As outdoor temperature increases, heat-emitting behaviors such as lying on the side and wallowing increase (Larson et al., 2003; Pedersen et al., 2003). Pigs also prefer to lie apart from each other (allowing heat to dissipate) when temperatures increase (Larson et al., 2003). Pedersen et al. (2003) determined that finishing pigs exhibit more heat-emitting behavior in the afternoon.

When straw is added to pig pens, aggressive behavior may occur less frequently because pigs spend more time and attention to their environment than other pigs (Morgan et al., 1998). Pigs outdoors may also be able to escape aggressive encounters with pen mates because stocking density is usually lower in this housing system (Lay et al., 2000). Fraser et al. (1991), found that straw bedding decreased rooting and chewing of pen mates, but bedding had little effect on other social behaviors such as mounting or aggressive biting. However, Morgan et al. (1998), found that bedding increased aggressive interactions, but had

no effect on mounting or attempts to prevent other pigs from reaching the feeder. According to Morgan et al. (1998), pigs on straw made more trips to the feeder than those without straw. However, those trips were of shorter duration. Fraser et al. (1991) found no difference in feeding patterns or overall daily activity of pigs with or without straw bedding, but pigs with straw concentrated more of their daily activity into the period when straw was fresh. Pigs on straw spend less time lying down than pigs without straw (Morgan et al., 1998). Additional time spent standing on straw was spent rooting the straw and interacting with other pigs. Lay et al. (2000) determined the welfare of pigs in hoops is better than that of pigs in confinement. Pigs in hoops exhibited more play behavior, which is considered a luxury only when other behavior needs of the pig have been satiated. Additionally, pigs in confinement performed more abnormal behaviors than pigs in hoops.

The housing system type may have an effect on the ability of the pig to cope with stress, especially during transportation and handling (Lambooij et al., 2004). Cortisol concentrations following handling or transportation are greater in pigs reared on concrete than bedding or outdoors, indicating pigs raised in conventional systems are more easily stressed, or less able to cope with stress (Geverink et al., 1999; Lay et al., 2000; Klont et al., 2001). Pigs that are unable to cope with stress during transportation or handling will be exhausted at the time of slaughter. As a result, much of the muscle glycogen will be depleted; pH will be high, resulting in dark and firm meat (Tarrant, 1989). Easily stressed pigs may also die during transportation. Number of yard dead (number of head per truckload) was less for pigs on deep bedding than in confinement, according to Gentry et al. (1999).

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CHAPTER 3. EFFECTS OF TRITICALE-BASED DIETS ON FINISHING PIG PERFORMANCE AND PORK QUALITY IN DEEP-BEDDED HOOP BARN¹

A paper to be submitted to the *Journal of Animal Science*

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Abstract

Effects of triticale-based diets on finishing pig performance and pork quality in deep-bedded hoop barns were evaluated. Triticale is a synthetic small grain resulting from an intergeneric cross between durum wheat and rye. The study consisted of four trials: two in winter (November 2003 through March 2004) and two in summer (May 2004 through September 2004) at the Iowa State University Western Research and Demonstration Farm, Castana, Iowa. Each trial consisted of six pens of ten pigs (five barrows, five gilts) in three small-scale hoop barns (6.0 x 10.8 m). Pens were randomly assigned one dietary treatment: 1) corn-soybean meal control, 2) 40% Trical 815 triticale diet (by weight) or 3) 80% Trical 815 triticale diet (by weight). The 40 and 80% triticale diets had corn and soybean meal

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added. Animals had *ad libitum* access to feed and water during the study. Pigs were started on experiment at approximately 72 kg and fed for 49 d. At the end of each trial all pigs were scanned for backfat thickness and loin muscle area. Barrows from one winter and one summer trial were evaluated for meat and fat quality and sensory evaluation of pork. End weights and ADG were greater during the winter than summer (treatment x season interaction $P < 0.01$) and decreased as triticale inclusion increased ($P < 0.001$). Feed intake was similar. Pigs fed the control diet had the greatest G:F, those fed the 80% triticale diet had the least, with pigs fed the 40% triticale diet having intermediate G:F. During the summer, pigs fed the control diet had more BF ($P < 0.05$) than those fed the triticale diets. Also during summer, pigs fed the control diet had the largest loin muscle area (LMA) ($47.5 \pm 1.72 \text{ cm}^2$); pigs fed the 40% triticale diet had intermediate LMA ($45.5 \pm 1.72 \text{ cm}^2$) and those fed the 80% triticale diet had the smallest LMA ($43.4 \pm 1.73 \text{ cm}^2$). Dietary treatment had no effect on carcass weight, BF, LMA, percentage lean of barrows or sensory evaluation or fatty acid profile of loin chops. Ultimate pH was higher ($P < 0.001$), percentage loin purge was less ($P < 0.05$) and shear force (kg) was less ($P < 0.05$) during summer than winter. Total monounsaturated fatty acids (MUFA) were greater ($P < 0.05$) and total PUFA in loins were less ($P < 0.01$) during the winter than summer. Replacing corn with triticale in finishing pig diets in hoops slightly decreased growth performance, but did not compromise pork quality.

Key Words: Deep litter swine housing, Triticale, Pork quality, Sensory evaluation, Finishing pigs

Introduction

Triticale (*Xtriticosecale* Wittmack) is a synthetic small grain that results from an intergeneric cross between durum wheat and rye. Triticale has more crude protein and an

amino acid profile that more closely matches the needs of the finishing pig than corn.

Utilization of triticale as an ingredient in swine diets will decrease the amount of soybean meal needed to meet the amino acid needs of the pig, compared to corn-based diets. There have been conflicting results on the effects of feeding triticale to finishing pigs. Some studies reported similar pig performance when triticale replaced corn as the dietary grain source (Hale et al., 1985; Jaikaran et al., 1998), while others have shown decreased performance (Myer et al., 1989; Brand et al., 1995).

Alternative swine production systems have become increasingly popular among pork producers and consumers. Producers are attracted to alternative production systems for many reasons including niche market access, animal welfare concerns, low-capital investments, versatility, health concerns of the producer and environmental considerations. One such alternative swine production system is deep-bedded hoop barns or hoops. Hoops costs per initial pig space are roughly one-third that of confinements (Honeyman et al., 2001). Studies have shown that pigs perform similarly in hoops and confinement (Honeyman and Harmon, 2003).

Triticale is being considered as a potential third crop in the Midwest. In order to become adopted by producers, an additional crop must meet two important criteria. The crop must have a readily accessible market and be profitable to produce. Triticale has shown potential as a feedstuff in swine diets. Producers who may find this to be an attractive crop may also raise swine in an alternative swine production system. The objective of the present study was to evaluate the effects of triticale-based diets in deep-bedded hoop barns on finishing pig performance and pork quality.

Materials and Methods

Animals and dietary treatments

Finishing pigs (n = 240) were used to evaluate the effects triticales-based diets fed in hoop barns had on pig performance, meat and fat quality and pork sensory attributes. The study consisted of four trials: two in winter (November 2003 through March 2004) and two in summer (May 2004 through September 2004) at the Iowa State University Western Research and Demonstration Farm, Castana, Iowa. Temperature data were collected at the farm using an automated weather station (Campbell Scientific, Logan, UT).

Each trial consisted of six pens of ten pigs (five barrows and five gilts) in three small-scale hoop barns (6.0 x 10.8 m). Small-scale hoop barns were previously described by Larson et al. (2003). Each test pen had one water space and two feeder spaces. Prior to allotment, pigs were fed corn-soybean meal diets as part of a larger group in a conventional deep-bedded hoop barn (9.1 x 18.3 m). Pigs were then moved to experimental pens. Pigs were vaccinated for swine influenza (Novartis Animal Health US, Inc., Larchwood, IA) according to label instructions. A two-week adjustment period was allowed for adaptation to triticales diets and experimental pens. Gender and genetic background were equalized across treatments. Pens were assigned one of three dietary treatments: 1) corn-soybean meal control (0% triticales), 2) 40% Trical 815 triticales diet (by weight) or 3) 80% Trical 815 triticales diet (by weight). The 40 and 80% triticales diets had corn and soybean meal added. All diets were ground with a hammer mill through a 0.64 cm screen and presented in meal form. Diets were isolysininc, based on calculated analysis. Diets were formulated to meet or exceed National Research Council (NRC, 1998) nutrient guidelines for finishing pigs. Composition and

calculated analysis of experimental diets are given in Table 1. Animals had *ad libitum* access to feed and water during the study.

The Trical 815 triticale used in the study was a winter triticale cultivar grown at the Iowa State University Western Research and Demonstration Farm, Castana, Iowa. Seed used to grow the triticale was donated by Resource Seeds, Inc., Gilroy, CA. Representative samples of Trical 815 triticale used were analyzed by proximate analysis for crude protein, crude fat, moisture, ash, and crude fiber according to AOAC (2000) methods. Complete amino acid profile of Trical 815 triticale was determined by AOAC methods (2000). Proximate analysis and amino acid profile determination of triticale were performed at the University of Missouri Experiment Station Chemical Laboratories, Columbia, MO. Triticale was screened for mycotoxin contamination using thin layer chromatography at the University of Missouri Veterinary Medicine Diagnostic Laboratory, Columbia, MO. The triticale was cleaned with a mechanical grain cleaner to minimize possible ergot sclerotia fed to pigs. Triticale straw was used as bedding in the deep-bedded hoop barns.

All pigs were from terminal Duroc boars crossed with predominately white sows and were porcine reproductive and respiratory syndrome (PRRS)-negative and high health status. The pigs were started on experiment at approximately 72 kg and fed for 49 d. Pigs were weighed at the beginning of the trial, 28 d and the end of the trial. Feed was weighed when placed in the feeders. Weighing occurred in the morning after feed was removed from the pigs for approximately 12 h. At 28 d and the end of study, the feeders were emptied and feed disappearance was recorded. Feed wastage was minimized by feeder adjustment, but not measured or estimated. Feed disappearance divided by the number of pigs per pen and then divided by the number of days on experiment equaled ADFI. Pig weights at the end of the

study less pig starting weights divided by number of days on study equaled ADG. G:F was calculated by dividing ADG by ADFI. Upon removal of pigs due to death or health problems, all pigs including removed pig were weighed. Feed was weighed and recorded and remaining pen continued on study.

At the end of each trial, all pigs were individually weighed and scanned by a National Swine Improvement Federation certified technician with an Aloka 500-V SSD ultrasound machine fitted with a 3.5-Mhz, 12.5-cm linear-array transducer (Corometrics Medical Systems, Inc., Wallingford, CT). Off-midline backfat and loin muscle area were measured from a cross-sectional image taken at the 10th rib. A sound-transmitting guide (Superflab, Mick Radio Nuclear Instruments, Inc., Bronx, NY) conforming to the pig's back was attached to the ultrasound probe and vegetable oil was used as a conducting material between the probe and skin. Barrows from one winter and one summer trial were used to evaluate the effects of the triticale-based diets fed in hoop barns on meat and fat quality and carcass characteristics. Animal housing and care was conducted in accordance with the *Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching* (FASS, 1999) and under the supervision of the Iowa State University Committee on Animal Care, log no. 11-2-5317-S.

Carcass Measures, Sensory Evaluation

Barrows from one winter and one summer trial were used to evaluate the effects triticale-based diets fed in hoop barns had on carcass traits, pork quality and pork sensory attributes. Barrows were transported to Swift and Co., Marshalltown, IA for processing. After slaughter and chilling, carcass traits were evaluated by trained personnel according to the National Pork Producers Council guidelines (NPPC, 1999). These data included carcass

composition traits, objective color measurements taken with a Minolta chromometer model CR-310 (Ramsey, NJ) for lightness (L^*), redness (a^*) and yellowness (b^*) and 22 h pH measured at the 10th rib with a Hanna Instruments model HI 9025 (Woonsocket, RI) glass penetrating pH electrode. Subjective firmness of the loin at the 10th rib was scored on a scale from 1 to 5, with higher values indicating greater firmness. Loins were removed from the carcass, vacuum packaged and transported to the Iowa State University Sensory Evaluation Lab. Loins were stored for 11 d in the winter trial and 14 d in the summer trial at 0 to 4° C. Following the storage period, each vacuum package was opened and both the loin and the amount of purge in the bag were weighed for the determination of loin purge percentage. Minolta color measures for lightness, redness, and yellowness were taken on a piece of loin backfat removed from the loin. Each loin was cut to provide a 2.54 cm thick boneless loin chop from the blade, center and sirloin end of the loin for evaluation of pH and color (Minolta L^* , a^* and b^*). Japanese color score was determined from one chop taken from the center of the loin. Two additional 2.54 cm thick boneless chops were removed from the center of the loin. One was placed in a Ziploc bag for the evaluation of chop purge. Chop purge was calculated by the weight of free liquid on a percentage basis that accumulated in the bag after 24 h storage at meat case temperature. The other chop was used for determination of marbling (% fat) by ether extraction. Two other 2.54 cm thick boneless chops were removed from the center of the loin and simultaneously broiled to 71°C in an electric oven broiler (Amana Model ARE 60) that had been preheated to 210°C. The temperature of each chop was individually monitored with thermocouples (Chromega/Alomega) attached to an Omega digital thermometer (Model DSS-650, Omega Engineering, Inc., Stamford, CN). Cooking losses were calculated from weights taken before

and after broiling and expressed as a percentage. Instrumental measurement of tenderness of one broiled chop was evaluated using shear force. Four 1.27 cm cores (equally spaced across the surface of the chop) were removed parallel to the muscle fiber orientation. Each core was sheared one time through the center. Shear force was measured using an Instron Universal Testing Machine (Model 4502, Canton, MA) with a Warner-Bratzler Shear (WBS) attachment. A 10 kilonewton load cell was used with a crosshead speed of 200 mm/min. Maximum shear force (kg) was measured as the peak height of each core. The four peaks were averaged and recorded. Sensory evaluation of the remaining broiled chop was performed using three highly trained professional sensory panelists. Training of the panel was previously described by Huff-Lonergan et al. (2002). Panelists were seated in individual booths with red lighting overhead to mask any differences in product color. Three 1.3 cm cubes were removed from the center of the broiled chop immediately after removal from the oven. The cubes were placed in preheated, individually coded glass Petri dishes and served to each panelist. Serving temperature of the samples was $65 \pm 2^{\circ}\text{C}$. samples were evaluated for degree of juiciness, tenderness, chewiness, pork flavor and off-flavor intensity using a 10-point category scale. The scale was anchored on the left end with a term representing a low degree of juiciness, tenderness, chewiness, pork flavor and off-flavor intensity. On the right end of the scale was a term representing a high degree of each characteristic. Room temperature deionized, distilled water and unsalted crackers were used to cleanse the palates of the panelists between samples. A 50 g sample of each loin was sent to the Iowa State University Nutritional Physiology Lab for chemical analysis.

Chemical analysis

Dry matter percentage of the chop was determined using a standard dry matter procedure of heating sample for 24 to 36 h at 100°C. Lipid percentage of the chop was determined using the wet tissue Folch lipid extraction method (Folch et al., 1957).

A quantity of each standard or sample that would provide 8 to 14 mg of fatty acids was placed in a 16 x 100 mm extraction tube. Standards and samples were dissolved in 650 μ L of n-butanol and vortexed at low speed for 1 min. While vortexing at low speed, 100 μ L of acetyl chloride were added slowly. Successful esterification depends on having an excess of reagent (n-butanol) and sufficiently acid conditions (Iverson and Sheppard, 1977). The extraction tubes were gassed with N_2 , covered tightly with Teflon-lined caps and placed on a heating block at 60°C for 0.5 h. After cooling the tubes to room temperature, 5 mL of 6% K_2CO_3 in water, (wt/v) were added to stop the reaction and to return the solution to about pH 7. After addition of K_2CO_3 , 1 mL of n-hexane was added to dissolve the esters. The tubes were vortexed for 0.5 min and centrifuged for 20 min at 2,500 x g. The lower layer (K_2CO_3 and butanol) was then aspirated by inserting a Pasteur pipette through the hexane layer. The remaining solution of butyl esters in hexane was washed three times with 5 mL of distilled water to remove excess butanol and K_2CO_3 . These washings prevent contamination of the column and prevent traces of butanol from masking the butyl-butyrate peak (Iverson and Sheppard, 1977). The upper hexane layer containing butyl esters was removed after the final washing and transferred to injection vials. Fatty acids were analyzed on a Varian 3350 gas chromatograph (Varian Chromatography Systems, Walnut Creek, CA) equipped with a split/splitless injector, a flame ionization detector and a SpTM 2560 fused silica capillary column (100 m x 0.25 mm x 0.20 μ m thickness; Supelco, Bellefonte, PA). The injection split

was set at 50 to 1 and head pressure was set at 46 psi. Injector and detector temperatures were set at 240°C. For determination of butyl esters, oven temperature was held at 80°C for 5 min immediately after injection of the sample, increased at 3°C/min until it reached 165°C, held for 10 min at this temperature and increased at 5°C/min to 240°C, which was held for 16 min. Thus, the total time per sample was 74 min.

Statistical analysis

Data were analyzed using the mixed model of SAS (SAS Inst. Inc., Cary, NC). The experimental unit was a pen of pigs. Pen to pen variability was used to test effects of treatment, season and treatment x season interaction. Least squares means were calculated and differences were considered statistically significant at $P < 0.05$.

Results

Triticale Analysis

The Trical 815 triticales in the present study was found to have no detectable mycotoxins (aflatoxin B1, ochratoxin A, zearalenone and vomitoxin) by thin layer chromatography (data not shown). Results of amino acid analysis (Table 2) show Trical 815 triticales had less amino acid content than the NRC (1998) values for triticales. However, when compared to the NRC (1998) values for amino acid content of corn, Trical 815 triticales had greater contents of all amino acids except leucine. Lysine content was determined to be 42% greater in Trical 815 triticales than corn (0.37 vs. 0.26%, respectively), according to analysis and NRC (1998) values.

Temperature

The mean temperature during the winter was -2.39°C, which was 1.5°C colder than the 30-yr average recorded at the ISU Western Research Farm. The mean temperature during

the summer was 19.2°C, which was 4.9°C colder than the 30-yr average. During the summer trial, the day before slaughter of barrows had a high temperature of 22.7°C, low temperature of 15.3°C and a relative humidity of 89.2%. The day of slaughter had a high temperature of 27.5°C, low temperature of 16.1°C and a relative humidity of 71.9%. During the winter trial, the day before slaughter of barrows had a high temperature of 11.7°C, low temperature of -0.8°C and a relative humidity of 67.6%. The day of slaughter had a high temperature of 2.2°C, low temperature of -8.5°C and a relative humidity of 55.3%.

Growth Performance

During the summer, pigs fed the 80% triticales diet had lighter ($P < 0.05$) start weights than those receiving the control or 40% triticales diet (Table 3). There were no differences in start weights for pigs during the winter. End weights and ADG were more during the winter than summer (treatment x season interaction; $P < 0.01$) and decreased as triticales inclusion increased ($P < 0.001$). No differences in ADFI between treatments were observed. There tended ($P = 0.10$) to be more feed consumed during the winter than summer. Pigs receiving the control diet had the greatest G:F. Pigs receiving the 80% triticales diet had the least G:F and those receiving the 40% triticales diet were intermediate. This was observed during both the summer and winter. During the summer, pigs fed the control diet had more backfat (BF) ($P < 0.05$) than those fed the 40 or 80% triticales diets. There were no differences in BF during the winter. During the summer, pigs fed the control diet had the largest loin muscle area (LMA) ($47.5 \pm 1.72 \text{ cm}^2$), pigs fed the 40% triticales diet had intermediate LMA ($45.5 \pm 1.72 \text{ cm}^2$) and those fed the 80% triticales diet had the smallest LMA ($43.4 \pm 1.73 \text{ cm}^2$). Three pigs died during the study, one from each dietary treatment.

Carcass Measures

There were no differences in carcass weight, BF measured at the 10th rib, LMA or percentage lean of barrows fed the control, 40 or 80 % triticale diets (Table 4). There tended ($P < 0.10$) to be lighter carcasses with less backfat during the winter than summer. Treatment had no effect on loin firmness, 22 h loin pH or loin Minolta L*. Loin pH (22 h) was higher during the summer than winter ($P < 0.05$). Loins from barrows were lighter and more yellow during the summer than winter, i.e., higher Minolta L* and b* values ($P < 0.05$). During the summer, loins from barrows fed the 80% triticale diet were more yellow than those from barrows fed the control or 40% triticale diet. During the winter, loins from barrows fed the control diet had higher a* values ($P < 0.05$) than barrows fed the triticale diets. During the winter, barrows fed the control diet had higher loin b* values ($P < 0.05$), indicating more yellow loin coloration, than barrows fed the 80% triticale, with values from barrows fed the 40% triticale diet intermediate. During the summer, one of the dead pigs removed from the study was a barrow, another barrow had an abscess and was not included and a third had locomotion problems and was excluded from the carcass and sensory evaluations. All three barrows in the summer season not included were fed the 80% triticale diet. During the winter one loin was not retrieved at the plant and two others were not evaluated due to blue leg. Blue leg is a plant indication of potential difficulty in carcass cutting, usually caused by broken backs or severe arthritis.

Meat Quality and Sensory Evaluation

Feeding triticale-based diets to barrows compared to corn-based diets in deep-bedded hoop barns had little effect on meat quality and sensory evaluation of pork measured 11 and 14 d post-slaughter during the winter and summer, respectively. During the summer, loins

from barrows receiving the 40% triticale diet had the lightest color, loins from barrows receiving the control diet had the darkest color, with loins from barrows fed the 80% triticale diet being intermediate, as indicated by Minolta L* values (Table 5). During the winter, loins from barrows fed the 80% triticale diet had the highest Minolta L* values, loins from barrows fed the control diet had the lowest L* values and loins from barrows fed the 40% triticale were intermediate. Fat from barrows receiving the control diet had lower Minolta L* values ($P < 0.05$) than those receiving the triticale diets during summer. There were seasonal effects on meat quality. Ultimate pH of loins was higher in the summer ($P < 0.001$) than winter. Loin chops had greater percentage of loin purge ($P < 0.05$) during the winter than summer. Shear force was greater in winter ($P < 0.05$) than summer, indicating more tender pork in the summer than winter. Japanese color scores were higher in the summer ($P < 0.05$) than winter, indicating darker loins. However, loin Minolta L* values were higher ($P < 0.01$) and b* values lower ($P < 0.05$) in the summer than winter, indicating lighter, less yellow loins in summer. Fat was darker ($P < 0.001$) and redder ($P < 0.05$) during the winter than summer, as indicated by fat Minolta L* and a* values. Sensory evaluation of loin chops from barrows showed loins to have higher scores for juiciness ($P < 0.001$) during the summer than winter. Juiciness scores were highest for loins from barrows fed the control diet, lowest for loins from barrows fed the 40% triticale diet and intermediate for loins from barrows fed the 80% triticale diet during the summer. Differences in tenderness, chewiness, pork flavor and off-flavor scores were not detected between seasons or treatments.

Fatty Acid Profile of Loins

Loins from barrows fed triticale-based diets had similar fatty acid profiles to those from barrows fed corn-based diets (Table 6). During the winter, behenic acid (22:0) content

of loins was greater from barrows fed the 80% triticale diet than from barrows fed the control diet and intermediate in loins from barrows fed the 40% triticale diet. All other fatty acid contents were similar between treatments. During the summer, the percentage of total lipids in wet tissue was higher ($P < 0.05$) in loins from barrows fed the control diet than the triticale diets. There were seasonal effects on fatty acids profiles of loins from barrows finished in deep-bedded hoop barns. The percentage of total lipids in loin muscle during the summer was greater ($P < 0.001$) than winter. Loins had more oleic acid (18:1) during the summer than winter. Linoleic (18:2), 11-14 eicosadienoic (20:2) and arachidonic/eicosatrienoic (20:3/20:4) acid concentrations were greater ($P < 0.01$) in the winter than summer. Total monounsaturated fatty acids (MUFA) were greater ($P < 0.05$) in the summer than winter. Total polyunsaturated fatty acids were greater ($P < 0.01$) in the winter than summer. Season had no effect on total saturated fatty acids. There were more ($P < 0.01$) n-6 fatty acids during the winter than summer.

Discussion

Triticale has more crude protein and a more balanced amino acid profile relative to the needs of the pig than corn. Feedstuffs with an amino acid profile that closely matches the needs of the pig can lower the amount of dietary protein needed. According to NRC (1998), this may decrease nitrogen excretion by the pig. The lysine content of Trical 815 triticale was determined to be 0.37%, slightly less than the NRC (1998) value of 0.39%. Previous research observed greater lysine content in triticale (King, 1980; Hale et al., 1985; Myer et al. 1990). King (1980) found the lysine content of triticale was 0.44%. Hale et al. (1985) determined Beagle 82 triticale had 0.48% lysine. Myer et al. (1990) detected 0.48, 0.43 and 0.41% lysine in Beagle 82 triticale, Florida 201 triticale and Florico triticale, respectively. There are

several factors that may influence the crude protein and amino acid content of triticale. According to Myer et al. (1986), greater than average rainfall during the early growing stages may result in below normal crude protein and amino acid contents. Protein and amino acid content may vary by triticale cultivar, location and year grown (Rundgren, 1998; Myer et al., 1989; Jaikaran et al., 1998). The Trical 815 triticale was grown in Iowa, whereas the Beagle 82, Florida 201 and Florico triticales were grown in Florida and Georgia. Newer triticale cultivars are higher yielding, with plumper grain of heavier test weight and greater starch content. Selection of these traits has lowered the protein content of the grain (Myer et al., 1996; Jaikaran et al., 1998). According to Jaikaran et al. (1998), cleaning triticale may reduce the protein content as smaller kernels, which are higher in protein than larger ones, may be removed, thereby decreasing protein content. Although the lysine content in Trical 815 triticale was less than that of older triticale varieties, the 40% triticale diet had 10.7% less soybean meal than the control diet (11.53 vs. 12.91%) and the 80% triticale diet had 25.3% less soybean meal than the control diet (9.64 vs. 12.91%). Because soybean meal is a relatively expensive ingredient in swine diets, feeding triticale as a replacement of corn in finishing pig diets may decrease dietary costs.

In the present study, end weight and ADG of finishing pigs decreased ($P < 0.001$) as triticale increased in the diets. Previous research has shown finishing pigs fed triticale-based diets have similar growth rates to those fed corn-based diets (Hale et al., 1985; Jaikaran et al., 1998). However, others have shown growth rate of finishing pigs decreased as triticale inclusion in diets increased (Myer et al., 1989; Brand et al., 1995). Brand et al. (1995) attributed the lower growth rate to lower dry matter intake of pigs fed triticale compared to corn. However, in the present study feed intake was similar between treatments. The 80%

triticale diet had 4.8% less metabolizable energy (3160 vs. 3320 kcal/kg) than the control diet, while the 40% triticale diet had 2.4% less metabolizable energy (3240 vs. 3320 kcal/kg) than the control diet. According to NRC (1998), finishing pigs fed *ad libitum* will compensate for lower energy dense diets by increasing feed consumption. However, this was not observed. In colder environments, pigs fed lower energy (higher fiber) diets are able to sustain growth rates comparable to pigs fed higher energy (lower fiber) diets. However, in hot environments, there is a greater chance of observing lower growth performance of pigs fed lower energy (higher fiber) diets than those fed higher energy (lower fiber) diets (NRC, 1998). In the present study it was observed that finishing pigs during summer fed the 80% triticale diet had 10.1% less ADG than those fed the control diet (892 vs. 802 ± 18 g/d), whereas during winter, finishing pigs fed the 80% triticale diet had only 3.0% less ADG (930 vs. 904 ± 18 g/d). It is hypothesized that the greater fiber content of triticale (NDF and ADF contents of triticale compared to corn 12.7 and 3.8 vs. 9.6 and 2.8%, respectively; NRC, 1998) provide a “gut fill” or feeling of satiety, reducing the urge for increased feed consumption to compensate for the lower dietary energy contents. Feedstuffs that are rich in fiber typically have a high heat increment, or heat of digestion. Heat increment aids in body thermoregulation in cold environments, as it reduces the amount of energy consumed in the diet that would be used for thermoregulation. However, in hot environments, diets rich in fiber (high heat increment) decrease feed intake, thereby negatively affecting performance (Patience et al., 1995). Because the pigs were reared in hoop barns, it is likely some straw bedding was consumed (Huenke and Honeyman, 2001). This may have furthered the fiber effect of triticale.

With similar feed intake and lower growth rate, gain:feed decreased ($P < 0.05$) as triticale inclusion increased. This was observed in both the summer and winter. Previous studies have reported similar gain:feed of finishing pigs fed triticale-based and corn-based diets (Brand et al., 1995; Myer et al., 1996; Jaikaran et al., 1998). Shimada et al. (1974) found gain:feed of pigs fed triticale-based diets was lower than that of pigs fed corn-based diets. Shimada et al. (1974) credited the poorer feed conversion to ergot contamination of triticale. The authors in that study determined the dietary ergot content to be 0.16%, above the recommended maximum level of 0.1% (Shimada et al., 1974). The triticale used in the present study was cleaned using a mechanical grain-cleaning machine prior to feeding to minimize ergot sclerotia consumption by finishing pigs. Therefore it is unlikely the reduced gain:feed observed for the triticale diets in the present study was due to ergot contamination. According to NRC (1998), increasing dietary crude fiber 1% may decrease gross energy digestibility by up to 3.5%. This suggests fiber may have had an effect on feed utilization of finishing pigs fed triticale-based diets. Probable consumption of bedding would have further aggravated this situation. Addition of fat or another energy dense dietary ingredient to the triticale diets may have supported similar growth gains and feed efficiency compared to the corn-soybean meal control.

According to ultrasound data, pigs fed the control diet had more backfat than pigs fed the triticale-based diets during summer. This was not observed during winter. Pigs fed the control diet during summer had the largest loin muscle areas, with pigs fed the 40% triticale diet having intermediate LMA and pigs fed the 80% triticale diets having the smallest LMA. Pigs had similar LMA regardless of dietary treatment during winter. It is unclear why these results were observed. Pigs fed triticale-based diets have had similar backfat thickness and

loin muscle areas to pigs fed corn-based diets in previous studies (Hale et al., 1985; Brand et al., 1995). According to Moeller and Christian (1998), ultrasonic backfat at the 10th rib and LMA are within ± 4 mm and ± 6.45 cm², respectively, of the corresponding carcass measurements 75.9 and 89.9% of the time.

Finishing pigs in the present study were reared in deep-bedded hoop barns that have little thermoregulation. Consequently, pig performance has been shown to vary according to season (Conner, 1993, 1994; Honeyman and Harmon, 2003). According to Larson et al. (2003), during the winter average high temperatures were 3.5°C warmer in the small-scale hoops used in this study than the average outside temperatures. During the summer, average temperatures were 0.9°C warmer in these small hoops than the average outside temperatures. Harmon and Xin (1996) found that the inside temperatures of conventional hoop barns were 3.9°C warmer during the winter and 1.7 °C cooler during the summer than outside temperatures.

In the present study, there tended ($P = 0.10$) to be more feed consumed during the winter than summer. Gain:feed tended ($P < 0.10$) to be lower during the winter than summer. This agrees with work by Honeyman and Harmon (2003) who found feed intake was greater during the winter than summer in deep-bedded hoop barns. Gain:feed was lower in the winter than summer in that study. This is likely due to an increased energy requirement of the pig to regulate body temperature during the winter. Because more energy is needed for maintenance, less energy is available to support growth.

Triticale may be used as an ingredient in finishing pig diets fed in deep-bedded hoop barns without compromising meat quality or carcass measurements of barrows. Barrows fed corn or triticale had similar carcass weights, backfat thickness, LMA and percentage lean.

This agrees with previous studies that showed similar carcass measurements of pigs fed triticale or corn as the dietary grain source (Hale et al., 1985; Brand et al., 1995; Myer et al., 1996). Dietary treatment had no effect on loin firmness, 22 h pH or loin Minolta L*. During the winter, loins from barrows fed the control diet had redder meat than barrows fed the triticale diets. During the winter, loins from barrows fed the control diet had more yellow loin color than loins from barrows fed the 80% triticale diet. Loins from barrows fed the 40% triticale diet had intermediate values for yellowness of loins. While there were differences in loin color, they were unlikely to greatly affect pork quality as measures were within acceptable ranges.

There has been limited research on the effects of feeding triticale to pigs and pork quality and palatability. According to Robertson et al. (1999), triticale can replace corn without decreasing pork quality or desirability. Robertson et al. (1999) found no differences in water-holding capacity, intramuscular fat content, color or pork eating desirability of pork from pigs fed triticale-based or corn-based diets. Melton (1990) observed replacement of corn up to 80% by triticale had no effect on pork flavor desirability. In the present study, feeding triticale-based diets compared to corn-based diets to barrows in deep-bedded hoop barns did not greatly affect meat quality and sensory evaluation of pork. It was observed in the present study that feeding triticale to barrows did not alter water-holding capacity as indicated by similar loin and chop purge percentages. Intramuscular fat content was not affected by dietary treatment. There were slight differences in loin color measured 11 and 14 d post-slaughter. During the summer, loins were lightest in barrows fed the 40% triticale diet, intermediate in loins from the 80% triticale diet and darkest in loins from control diet. During the winter, loins were lightest in barrows fed the 80% triticale diet, intermediate in the 40%

triticale diet and darkest in the control diet. The only difference in sensory evaluation of pork from barrows fed triticale or corn was during the summer when loin chops from barrows fed the control diet had greater scores for juiciness than loin chops from barrows fed the 40% triticale diet, with loin chops from barrows fed the 80% triticale diet having intermediate scores for juiciness. This was not observed during the winter.

Season or temperature had an effect on several meat quality characteristics. Few researchers have determined the seasonal effects of finishing pigs in deep-bedded hoop barns. Work has been conducted evaluating different housing systems i.e. pork from pigs reared in confinement versus outdoors. Loin chops from pigs finished outdoors may have a lower shear force value than loin chops from pigs finished indoors (Gentry, 1999; Gentry 2002b). However, other studies have shown no difference in shear force value of loin chops from pigs raised outdoors and indoors (Gentry et al., 2002a; Gentry et al., 2004). In the present study, shear force was greater during the winter than summer, indicating less tender pork from pigs finished in deep-bedded hoop barns during the winter. However, according to sensory evaluation, there were no detectable differences in tenderness of loin chops during summer or winter. Ultimate pH was greater in the summer than winter. As pH decreases, the water-holding capacity of pork decreases, or purge will increase. This is evident as loin purge percentage was greater in the winter than summer. It should be noted that most off-flavor scores were the result of sour tastes. According to Jeremiah et al. (1990), lactic acid builds up in meat as rapid post-mortem glycolysis occurs. This lactic acid build up results in a sour taste during mastication. However, while ultimate pH was lower and purge was greater in the winter than summer, there were no differences in off-flavor scores. Klont et al. (2001) detected pigs reared in bedded systems had a greater 24 h pH than those reared on slats (in

confinement), consequently, pigs reared on slats had greater percentage drip loss. Lambooij et al. (2004) attributed greater water-holding capacity of pigs raised on bedding to their ability to cope with stress better than pigs raised in confinement. Because stocking densities are usually lower in bedded systems than confinements, pigs can move about freely, becoming more resistant to exhaustion, having a lower post-mortem glycolytic rate than pigs in conventional systems, thereby improving water-holding capacity (Lambooij et al., 2004). Other studies have shown similar muscle pH and water-holding capacity or purge loss in differing housing systems (Gentry et al., 2002b; Gentry et al., 2004).

Pork from pigs reared outdoors has been shown to be redder with no differences in lightness or yellow compared to pigs reared indoors, according to Minolta a^* , L^* and b^* scores, respectively (Gentry et al., 2004). However, Gentry et al. (2002b) found pork from pigs raised outdoors had a greater Minolta L^* score, indicating lighter meat. In the present study, loins were darker (lower Minolta L^* scores) and more yellow (higher Minolta b^* scores) in the winter. However, Japanese color score values were greater in the summer than winter, indicating pork was darker in the summer.

While housing systems were not evaluated in the present study, a study by Gentry et al. (1999) found pork from pigs raised on deep-bedding had greater scores for tenderness, juiciness, flavor intensity and overall mouthfeel, compared to pork from pigs raised in conventional systems. However, other studies have shown no difference in sensory evaluation of pork with respect to housing system used to raise finishing pigs (Gentry et al., 2002a,b; Gentry et al., 2004).

Feeding triticale-based and corn-based diets to barrows in deep-bedded hoop barns resulted in similar loin chop fat content and fatty acid profiles. During the summer, the total

lipid content of loin chops from barrows fed the control diet was less than that of loin chops from barrows fed either triticale diet. This was not detected during the winter. The only fatty acid affected by dietary treatment was behenic acid (22:0). During the winter, behenic acid content was greatest in loin chops from barrows fed the 80% triticale diet, least in loins from barrows fed the control diet and intermediate in loins from barrows fed the 40% triticale diet. Melton (1990) observed feeding pigs triticale increased the percentages of palmitoleic (16:1) and linoleic (18:2) acids and decreased the percentages of palmitic and stearic acids in the longissimus muscle. The present study did not observe these differences.

Season affected fatty acid profiles of loin chops from barrows in deep-bedded hoop barns. Percentage of total lipids in loins was greater during the summer than winter. This may be due to fat mobilization of pigs during winter to be used as an energy source for thermoregulation. During the summer, MUFA content was greater and PUFA content was less than during the winter. Season did not affect SFA contents. These results are in agreement with previous work evaluating temperature and fatty acid contents of lipids (Bee et al., 2004; Rinaldo and Mourot, 2004). Bee et al. (2004) found that pigs finished outdoors at 22°C had increased levels of MUFA and decreased levels of PUFA than pigs finished at 5°C. SFA content of intramuscular lipid was similar for the two temperatures. Rinaldo and Mourot determined that higher temperatures resulted in lower concentrations of MUFA and higher concentrations of PUFA in backfat.

Implications

Effects of triticale-based diets in deep-bedded hoop barns were evaluated in this study. Increasing the amount of triticale in finishing pig diets decreased dietary soybean meal and dicalcium phosphate levels. This may reduce dietary costs. Pigs fed triticale had as much

as 10% less average daily gain and as much as 13% poorer feed conversion, particularly at the greater inclusion rate (80% of the diet). This may offset the potentially lower dietary costs. Triticale can be fed to pigs without compromising pork or fat quality. There was no difference in pork eating quality from pigs fed corn-based or triticale-based diets, according to a highly trained sensory evaluation panel. Further research on triticale-based swine diets is warranted. Triticale-based diets in deep-bedded hoop barns should be evaluated when dietary fat is added, as finishing pig performance may be enhanced. An economic analysis should be conducted on utilization of triticale as a feedstuff in swine diets fed to finishing pigs in deep-bedded hoop barns. From the results of this study, triticale has potential as a feed grain crop in integrated crop and livestock enterprises in the Midwest U. S.

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Table 1. Composition of diets fed to finishing pigs in deep-bedded hoop barns, as-fed basis

<u>Ingredient, %</u>	<u>Control^a</u>	<u>40% Triticale^a</u>	<u>80% Triticale^a</u>
Corn	85.00	46.50	8.50
Triticale	0.00	40.00	80.00
Soybean meal (48% CP)	12.91	11.53	9.64
Dicalcium phosphate	0.60	0.33	0.07
Limestone	0.90	1.05	1.20
Salt	0.34	0.34	0.34
Vitamin premix ^b	0.20	0.20	0.20
Mineral premix ^c	0.05	0.05	0.05
<u>Calculate analysis</u>			
Crude protein, %	12.90	13.60	14.10
Lysine, %	0.61	0.62	0.61
Ca, %	0.53	0.54	0.55
Available P, %	0.17	0.17	0.17
ME, kcal/kg	3320	3240	3160

^aContained 0.5 g/kg aureomycin chlortetracycline (Alpharma Inc., Fort Lee, NJ).

^bPremix supplied vitamins to meet or exceed NRC (1998) requirements for finishing pigs.

^cPremix supplied minerals to meet or exceed NRC (1998) requirements for finishing pigs.

Table 2. Amino acid content (percentage) of Trical 815 triticale, triticale and corn, as-fed basis

Amino acid	Trical 815 triticale ^a	Triticale ^b	Corn ^b
Arginine	0.57	0.57	0.37
Histidine	0.26	0.26	0.23
Isoleucine	0.36	0.39	0.28
Leucine	0.70	0.76	0.99
Lysine	0.37	0.39	0.26
Methionine	0.18	0.20	0.17
Cystine	0.27	0.26	0.19
Phenylalanine	0.49	0.49	0.39
Tyrosine	0.23	0.32	0.25
Threonine	0.32	0.36	0.29
Tryptophan	0.12	0.14	0.06
Valine	0.51	0.51	0.39

^aAmino acid analyses conducted by University of Missouri Experiment Station Chemical Laboratories, Columbia, MO.

^bValues from NRC (1998).

Table 3. Performance of finishing pigs fed triticale-based diets in deep-bedded hoop barns during summer and winter^a

Item	Summer			Winter			P-value ^b		
	Control	40%	80%	Control	40%	80%	T	S	T x S
No. of pigs	40	40	39	39	39	40	-	-	-
No. of pens	4	4	4	4	4	4	-	-	-
Start wt, kg	72.8 ^o ± 1.87	73.1 ^o ± 1.87	70.8 ^p ± 1.87	72.3 ± 1.87	72.4 ± 1.87	71.2 ± 1.87	0.02	0.94	0.26
End wt, kg	116.5 ^u ± 2.17	114.5 ^v ± 2.17	110.2 ^w ± 2.18	117.3 ^t ± 2.18	116.3 ^s ± 2.18	115.1 ^t ± 2.17	< 0.001	0.50	< 0.01
ADG, g/d	892 ^u ± 18	846 ^v ± 18	802 ^w ± 18	930 ^t ± 18	901 ^s ± 18	904 ^s ± 18	< 0.001	0.12	< 0.01
ADFI, kg/d	3.51 ± 0.18	3.49 ± 0.18	3.53 ± 0.18	3.91 ± 0.18	4.11 ± 0.18	4.35 ± 0.18	0.27	0.10	0.35
Gain:feed g/kg	254 ^o ± 7	243 ^{op} ± 7	227 ^p ± 7	239 ^t ± 7	221 ^{rs} ± 7	209 ^s ± 7	0.04	0.09	0.90
BF, mm ^c	18.3 ^o ± 0.06	17.6 ^p ± 0.06	17.0 ^p ± 0.06	17.7 ± 0.06	20.5 ± 0.06	19.6 ± 0.06	0.15	0.16	0.03
LMA, cm ^{2,c}	47.5 ^o ± 1.72	45.5 ^{op} ± 1.72	43.4 ^p ± 1.73	47.6 ± 1.73	44.8 ± 1.73	45.0 ± 1.72	0.04	0.91	0.47

^aSummer = April through September; Winter = October through March.

^bP values for treatment (T), season (S) and interaction effects (T x S).

^cFrom ultrasound scan data.

^{opqrst}Within a season, LS means without a common superscript letter differ ($P < 0.05$) during summer (^{opq}) or during winter (^{rst}).

^{uvwxyz}Within a season, LS means without a common superscript letter differ ($P < 0.01$) during summer (^{uvw}) or during winter (^{xyz}).

Table 4. Carcass and meat quality characteristics of barrows fed triticale-based diets in deep-bedded hoop barns during summer and winter^{a,b}

Item	Summer			Winter			P-value ^c		
	Control	40%	80%	Control	40%	80%	T	S	T x S
No. of barrows	10	10	7	9	9	9	-	-	-
Carcass wt, kg	98.6 ± 4.34	99.1 ± 4.34	89.7 ± 4.63	88.1 ± 4.39	89.3 ± 4.39	85.7 ± 4.39	0.34	0.06	0.73
10th rib backfat, mm	22.0 ± 1.70	22.9 ± 1.70	20.6 ± 1.87	17.5 ± 1.73	21.2 ± 1.73	18.2 ± 1.73	0.33	0.09	0.71
LMA, cm ²	56.7 ± 2.01	56.7 ± 2.01	52.4 ± 2.39	55.0 ± 2.12	53.8 ± 2.12	49.4 ± 2.12	0.18	0.23	0.95
Lean, %	52.0 ± 1.00	51.7 ± 1.00	52.5 ± 1.13	54.8 ± 1.03	52.4 ± 1.03	53.7 ± 1.03	0.43	0.12	0.61
Firmness (loin) ^d	2.00 ± 0.22	1.90 ± 0.22	2.52 ± 0.25	2.44 ± 0.22	2.38 ± 0.22	2.28 ± 0.22	0.55	0.27	0.29
22 h loin pH	5.79 ± 0.03	5.77 ± 0.03	5.78 ± 0.04	5.75 ± 0.03	5.70 ± 0.03	5.68 ± 0.03	0.43	0.04	0.75
Loin Minolta L ^{*e}	52.0 ± 0.47	52.4 ± 0.51	52.2 ± 0.59	49.4 ± 0.51	51.3 ± 0.51	51.2 ± 0.51	0.18	0.04	0.35
Loin Minolta a ^{*e}	17.01 ± 0.24	16.64 ± 0.25	17.12 ± 0.29	17.74 ^f ± 0.25	16.87 ^g ± 0.25	16.87 ^g ± 0.25	0.11	0.31	0.23
Loin Minolta b ^{*e}	3.43 ^o ± 0.08	3.26 ^o ± 0.08	3.70 ^p ± 0.08	3.45 ^r ± 0.08	3.12 ^s ± 0.08	3.36 ^{rs} ± 0.08	0.01	0.04	0.14

^aCharacteristics measured at packing plant.

^bSummer = April through September; Winter = October through March.

^cP values for treatment (T), season (S) and interaction effects (T x S).

^dFirmness 1 to 5 scale, higher values indicate greater firmness.

^eHigher L* values indicate a lighter color, higher a* values indicate a redder color and higher b* values indicate a more yellow color.

^{opqrst}Within a season, LS means without a common superscript letter differ ($P < 0.05$) during summer (^{opq}) or during winter (^{rst}).

^{uvwxyz}Within a season, LS means without a common superscript letter differ ($P < 0.01$) during summer (^{uvw}) or during winter (^{xyz}).

Table 5. Meat quality and sensory evaluation of loin chops from barrows fed triticales-based diets in deep-bedded hoop barns during summer and winter^{a,b}

Item	Summer			Winter			P-value ^c		
	Control	40%	80%	Control	40%	80%	T	S	T x S
No. of loins	10	10	7	9	9	9	-	-	-
Cook loss, %	20.3 ± 1.56	21.0 ± 1.56	23.3 ± 1.74	22.3 ± 1.60	21.3 ± 1.60	22.1 ± 1.60	0.62	0.79	0.63
Loin purge, %	0.48 ± 0.18	0.67 ± 0.18	0.18 ± 0.24	1.65 ± 0.21	1.72 ± 0.21	1.88 ± 0.21	0.72	< 0.01	0.38
Chop purge, %	1.7 ± 0.55	2.1 ± 0.55	2.1 ± 0.63	2.6 ± 0.57	2.8 ± 0.57	2.9 ± 0.57	0.85	0.15	0.98
Marbling, % fat ^d	1.95 ± 0.16	2.00 ± 0.16	2.30 ± 0.19	1.78 ± 0.17	1.89 ± 0.17	1.78 ± 0.17	0.63	0.11	0.51
Japanese color score ^e	3.00 ± 0.11	2.85 ± 0.11	2.99 ± 0.13	2.78 ± 0.12	2.66 ± 0.12	2.50 ± 0.12	0.46	0.03	0.46
Ultimate pH ^f	5.62 ± 0.02	5.60 ± 0.02	5.61 ± 0.02	5.51 ± 0.02	5.49 ± 0.02	5.49 ± 0.02	0.58	< 0.001	0.89
WBS shear force, kg ^g	2.58 ± 0.09	2.65 ± 0.09	2.40 ± 0.12	4.38 ± 0.10	4.53 ± 0.10	4.05 ± 0.10	0.27	0.03	0.67
Loin Minolta L* ^h	57.0 ^u ± 0.27	58.6 ^v ± 0.27	57.6 ^{uv} ± 0.36	56.2 ^t ± 0.32	56.7 ^{rs} ± 0.32	57.4 ^s ± 0.32	0.01	< 0.01	0.05
Loin Minolta a* ^h	18.18 ± 0.15	17.82 ± 0.15	18.06 ± 0.19	18.20 ± 0.17	18.45 ± 0.17	17.96 ± 0.17	0.57	0.21	0.12
Loin Minolta b* ^h	4.7 ± 0.37	4.9 ± 0.37	4.7 ± 0.41	5.3 ± 0.38	5.9 ± 0.38	5.7 ± 0.38	0.69	0.03	0.82
Fat Minolta L* ^h	79.1 ^o ± 0.65	82.9 ^p ± 0.65	83.4 ^p ± 0.82	76.4 ± 0.71	75.7 ± 0.71	75.7 ± 0.71	0.11	< 0.001	0.03
Fat Minolta a* ^h	11.3 ± 0.61	10.1 ± 0.61	10.2 ± 0.70	12.6 ± 0.63	12.3 ± 0.63	11.3 ± 0.63	0.25	0.03	0.64
Fat Minolta b* ^h	7.9 ± 0.47	7.2 ± 0.47	7.2 ± 0.53	8.6 ± 0.48	8.1 ± 0.48	8.1 ± 0.48	0.46	0.12	0.96
Juiciness score ⁱ	7.00 ^o ± 0.15	6.30 ^p ± 0.15	6.59 ^{op} ± 0.20	5.63 ± 0.18	5.68 ± 0.18	5.27 ± 0.18	0.15	< 0.001	0.13
Tenderness score ⁱ	7.6 ± 0.38	6.8 ± 0.38	7.6 ± 0.47	6.9 ± 0.41	6.4 ± 0.41	6.7 ± 0.41	0.30	0.09	0.82
Chewiness score ⁱ	2.30 ± 0.25	2.50 ± 0.25	2.00 ± 0.30	2.55 ± 0.26	2.79 ± 0.26	2.89 ± 0.26	0.65	0.07	0.47
Pork flavor score ⁱ	2.00 ± 0.12	1.90 ± 0.12	2.15 ± 0.15	2.22 ± 0.13	2.11 ± 0.13	1.89 ± 0.13	0.71	0.61	0.23
Off-flavor score ⁱ	3.9 ± 0.66	4.2 ± 0.66	3.5 ± 0.73	3.9 ± 0.67	4.9 ± 0.67	4.4 ± 0.67	0.57	0.35	0.80

^aCharacteristics measured in laboratory.

^bSummer = April through September; Winter = October through March.

^cP values for treatment (T), season (S) and interaction effects (T x S).

^dFat concentration in the raw loin determined by ether extraction.

^eJapanese color bar 1 to 6 scale, 1 = extremely light, 6 = extremely dark.

^fUltimate pH taken at 11 d during the winter trial and 14 d during the summer trial.

^gShear force value is average of four maximum force peaks.

^hHigher L* values indicate a lighter color, higher a* values indicate a redder color and higher b* values indicate a more yellow color.

ⁱScores on a 1 to 10 scale. Low scores represent low degrees of characteristics, high scores represent high degrees of characteristics.

^{opqrst}Within a season, LS means without a common superscript letter differ ($P < 0.05$) during summer (^{opq}) or during winter (^{rst}).

^{uvwxyz}Within a season, LS means without a common superscript letter differ ($P < 0.01$) during summer (^{uvw}) or during winter (^{xyz}).

Table 6. Nutrient content and fatty acid profile of loin chops from barrows fed triticale-based diets in deep-bedded hoop barns during summer and winter^a

Item	Summer			Winter			P-value ^b		
	Control	40%	80%	Control	40%	80%	T	S	T x S
No. of loins	10	10	7	9	9	9	-	-	-
DM, g/100 g	27.6 ± 0.42	27.8 ± 0.42	27.4 ± 0.46	26.9 ± 0.43	28.1 ± 0.43	27.7 ± 0.43	0.33	0.97	0.48
Lipid, % wet tissue	3.05 ^e ± 0.16	3.76 ^p ± 0.16	3.84 ^p ± 0.21	2.77 ± 0.18	2.93 ± 0.18	2.60 ± 0.18	0.07	< 0.001	0.07
14:0 ^c	1.58 ± 0.25	1.79 ± 0.25	1.45 ± 0.28	1.46 ± 0.26	1.43 ± 0.26	1.45 ± 0.26	0.83	0.46	0.79
16:0	27.15 ± 0.25	27.32 ± 0.25	27.06 ± 0.31	27.49 ± 0.27	27.76 ± 0.27	27.69 ± 0.27	0.70	0.07	0.87
16:1	4.1 ± 0.33	4.1 ± 0.33	4.3 ± 0.38	3.7 ± 0.34	3.9 ± 0.34	3.8 ± 0.34	0.94	0.30	0.92
17:0	0.34 ± 0.17	0.38 ± 0.17	0.13 ± 0.19	0.19 ± 0.18	0.14 ± 0.18	0.16 ± 0.18	0.76	0.46	0.75
18:0	12.2 ± 0.80	13.7 ± 0.80	12.0 ± 0.90	11.8 ± 0.82	11.7 ± 0.82	11.7 ± 0.82	0.57	0.24	0.54
18:1	47.4 ± 0.45	46.1 ± 0.45	47.4 ± 0.58	45.7 ± 0.50	45.8 ± 0.50	45.6 ± 0.50	0.45	0.01	0.30
18:2(n-6)	4.6 ± 0.56	4.0 ± 0.56	5.0 ± 0.64	6.7 ± 0.58	6.0 ± 0.58	6.3 ± 0.58	0.46	< 0.01	0.73
18:3(n-3)	0.88 ± 0.17	1.19 ± 0.17	0.82 ± 0.21	0.63 ± 0.18	0.92 ± 0.18	0.65 ± 0.18	0.20	0.16	0.96
20:0	0.19 ± 0.07	0.16 ± 0.07	0.20 ± 0.08	0.34 ± 0.07	0.20 ± 0.07	0.29 ± 0.07	0.51	0.16	0.76
20:2(n-6)	0.09 ± 0.03	0.10 ± 0.03	0.14 ± 0.03	0.23 ± 0.03	0.23 ± 0.03	0.21 ± 0.03	0.76	< 0.01	0.44
22:0	0.16 ± 0.04	0.13 ± 0.04	0.18 ± 0.05	0.14 ^r ± 0.04	0.20 ^{rs} ± 0.04	0.29 ^s ± 0.04	0.21	0.17	0.34
20:3/20:4(n-3/n-6)	1.16 ± 0.10	0.89 ± 0.10	1.24 ± 0.12	1.43 ± 0.11	1.49 ± 0.11	1.75 ± 0.11	0.06	< 0.001	0.31
22:6(n-3)	0.11 ± 0.04	0.12 ± 0.04	0.07 ± 0.05	0.13 ± 0.05	0.15 ± 0.05	0.18 ± 0.05	0.97	0.22	0.65
SFA ^d	41.7 ± 1.10	43.5 ± 1.10	41.1 ± 1.27	41.4 ± 1.14	41.4 ± 1.14	41.6 ± 1.14	0.60	0.53	0.54
MUFA ^e	51.5 ± 0.58	50.2 ± 0.58	51.6 ± 0.72	49.4 ± 0.63	49.8 ± 0.63	49.4 ± 0.63	0.67	0.01	0.33
PUFA ^f	6.9 ± 0.71	6.3 ± 0.71	7.3 ± 0.82	9.2 ± 0.74	8.8 ± 0.74	9.1 ± 0.74	0.67	< 0.01	0.87
Total n-3	2.15 ± 0.16	2.20 ± 0.16	2.13 ± 0.21	2.20 ± 0.18	2.55 ± 0.18	2.59 ± 0.18	0.45	0.07	0.50
Total n-6	5.9 ± 0.66	5.0 ± 0.66	6.4 ± 0.77	8.4 ± 0.69	7.7 ± 0.69	8.3 ± 0.69	0.36	< 0.01	0.79

^aSummer = April through September; Winter = October through March.

^bP values for treatment (T), season (S) and interaction effects (T x S).

^cFatty acids are expressed as g/100 g total fatty acids. Fatty acids were designated by the number of carbon atoms followed by the number of double bonds. The position of the first double bond relative to the methyl (n) end of the molecule was also included.

^dSFA = saturated fatty acids.

^eMUFA = monounsaturated fatty acids.

^fPUFA = polyunsaturated fatty acids.

^{opqrst}Within a season, LS means without a common superscript letter differ (P < 0.05) during summer (^{opq}) or during winter (^{rst}).

CHAPTER 4. GENERAL CONCLUSIONS

Triticale may be used as an ingredient in finishing pig diets fed in deep-bedded hoop barns. The study consisted of four trials: two in winter (November 2003 through March 2004) and two in summer (May 2004 through September 2004) at the Iowa State University Western Research and Demonstration Farm, Castana, Iowa. Each trial consisted of six pens of ten pigs (five barrows and five gilts) in three small-scale hoop barns (6.0 x 10.8 m). Pens were randomly assigned one of three dietary treatments: 1) corn-soybean meal control (0% triticale), 2) 40% Trical 815 triticale diet (by weight) or 3) 80% Trical 815 triticale diet (by weight). The 40 and 80% triticale diets had corn and soybean meal added. The pigs were started on experiment at approximately 72 kg and fed for 49 d. At the end of each trial, all pigs were individually weighed and scanned by a National Swine Improvement Federation certified technician. Barrows from one winter and one summer trial were used to evaluate the effects triticale-based diets fed in hoop barns had on carcass traits, pork quality and pork sensory attributes.

Trical 815 triticale was found to have no detectable mycotoxins by thin layer chromatography. Lysine content was determined to be 42% greater in Trical 815 triticale than corn (0.37 vs. 0.26%, respectively). Three pigs died during the study, one in each dietary treatment. End weights and ADG were greater during the winter than summer (treatment x season interaction; $P < 0.01$) and decreased as triticale inclusion increased ($P < 0.001$). No differences in feed intake between treatments were observed. There tended ($P = 0.10$) to be more feed consumed during the winter than summer. Pigs receiving the control diet had the greatest gain:feed, those receiving the 80% triticale diet had the least gain:feed and those receiving the 40% triticale diet were intermediate. This was observed during the

summer and winter. During the summer, pigs fed the control diet had more backfat (BF) ($P < 0.05$) than those fed the 40 or 80% triticale diets. BF was 18.3 , 17.6 and 17.0 ± 0.06 mm for the pigs receiving the control, 40 and 80% triticale diets, respectively. There were no differences detected in backfat during the winter. During the summer, pigs fed the control diet had the largest loin muscle area (LMA) (47.5 ± 1.72 cm²), pigs fed the 40% triticale diet had intermediate LMA (45.5 ± 1.72 cm²) and those fed the 80% triticale diet had the smallest LMA (43.4 ± 1.73 cm²).

There were no differences in carcass weight, backfat measured at the 10th rib, LMA or percentage lean of barrows fed the control, 40 or 80 % triticale diets (Table 4). There tended ($P < 0.10$) to be lighter carcasses with less backfat during the winter than summer. Treatment had no effect on loin firmness, 22 h loin pH or loin Minolta L*. Loin pH (22 h), Minolta L* and a* values of barrows was higher during the summer than winter ($P < 0.05$). Loins from barrows were lighter and redder during the summer than winter. Loins from barrows were more yellow during the winter than summer (higher Minolta b* values; $P < 0.05$). During the winter, loins from barrows fed the control diet had higher a* values ($P < 0.05$) than barrows fed the triticale diets. During the winter, barrows fed the control diet had higher loin b* values ($P < 0.05$), indicating more yellow loin coloration, than barrows fed the 80% triticale, with values from barrows fed the 40% triticale diet intermediate.

Feeding triticale-based diets to barrows compared to corn-based diets in deep-bedded hoop barns had little effect on meat quality and sensory evaluation of pork measured 11 and 14 d post-slaughter during the winter and summer, respectively. There were seasonal effects on meat quality. Ultimate pH of loins was higher in the summer ($P < 0.001$) than winter. Loin chops had greater percentage of loin purge ($P < 0.05$) during the winter than summer.

Shear force was greater in winter ($P < 0.05$) than summer, indicating more tender pork the summer than winter. Japanese color scores were higher in the summer ($P < 0.05$) than winter, indicating darker loins. However, loin Minolta L^* values were higher in the summer ($P < 0.05$) than winter, indicating lighter loins in summer. Fat was darker, redder and more yellow ($P < 0.05$ and < 0.001) during the winter than summer, as indicated by fat Minolta L^* , a^* and b^* values. Sensory evaluation of loin chops from barrows showed loins to have higher scores for juiciness ($P < 0.001$) during the summer than winter. Juiciness scores were highest for loins from barrows fed the control diet, lowest for loins from barrows fed the 40% triticale diet and intermediate for loins from barrows fed the 80% triticale diet. Differences in tenderness, chewiness, pork flavor and off-flavor scores were not detected between seasons or treatments.

Loins from barrows fed triticale-based diets had similar fatty acid contents to those from barrows fed corn-based diets (Table 6). During the winter, behenic (22:0) content of loins from barrows fed the 80% triticale diet was greatest, lowest in loins from barrows fed the control diet and intermediate in loins from barrows fed the 40% triticale diet. All other fatty acid contents were similar between treatments. During the summer, the percentage of total lipids in wet tissue was higher ($P < 0.05$) in loins from barrows fed the control diet than the triticale diets. There were seasonal effects on fatty acids profiles of loins from barrows finished in deep-bedded hoop barns. Percentage of total lipids in loins during the summer was greater ($P < 0.001$) than winter. Loins had more oleic acid (18:1) during the summer than winter. Linoleic (18:2), 11-14 eicosadienoic (20:2) and arachidonic/eicosatrienoic (20:3/20:4) concentrations were greater ($P < 0.01$) in the winter than summer. Total monounsaturated fatty acids (MUFA) were greater ($P < 0.05$) in the summer than winter.

Total polyunsaturated fatty acids were greater ($P < 0.01$) in the winter than summer. Season had no effect on total saturated fatty acids. There were more ($P < 0.01$) n-6 fatty acids during the winter than summer.

The 40% triticale diet had 10.7% less soybean meal than the control diet (11.53 vs. 12.91%) and the 80% triticale diet had 25.3% less soybean meal than the control diet (9.64 vs. 12.91%). Because soybean meal is a relatively expensive ingredient in swine diets, feeding triticale as a replacement of corn in finishing pig diets may decrease dietary costs. Because growth rate and feed efficiency of finishing pigs fed the triticale diets were poorer, the reduction in dietary costs due to less soybean meal is likely offset. However, triticale-based diets did not compromise meat quality or pork sensory attributes, therefore it has potential as an ingredient in finishing pig diets.

Increasing the amount of triticale in finishing pig diets decreased dietary soybean meal and dicalcium phosphate levels. This may reduce dietary costs. Pigs fed triticale had as much as 10% less average daily gain and as much as 13% poorer feed conversion, particularly at the greater inclusion rate (80% of the diet). This may offset the potentially lower dietary costs. Triticale can be fed to pigs without compromising pork or fat quality. There was no difference in pork desirability from pigs fed corn-based or triticale-based diets, according to a highly trained sensory evaluation panel. Further research is warranted in this area. A study in which diets are equalized on a lysine-to-metabolizable energy ratio is suggested. The energy content of the triticale diets in the present study was less than that of the control. Added fat may improve nutrient digestibility or utilization, improving growth rate and feed efficiency.

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APPENDIX: SAMPLE ANALYSIS OF VARIANCE

The Mixed Procedure

Model Information

Data Set	WORK.SET1
Dependent Variable	Hot_Wt
Covariance Structure	Variance Components
Estimation Method	Type 3
Residual Variance Method	Factor
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Satterthwaite

Class Level Information

Class	Levels	Values
pen	6	1 2 3 4 5 6
Treatment	3	0 40 80
Season	2	Summer Winter

Dimensions

Covariance Parameters	2
Columns in X	12
Columns in Z	12
Subjects	1
Max Obs Per Subject	54

Number of Observations

Number of Observations Read	54
Number of Observations Used	54
Number of Observations Not Used	0

Type 3 Analysis of Variance

Source	DF	Sum of Squares	Mean Square	Expected Mean Square
Treatment	2	446.237671	223.118835	Var (Residual) + 4.2577 Var (pen*Treatment (Season)) +Q (Treatment,Treatment*Season)
Season	1	784.158460	784.158460	Var (Residual) + 4.2105 Var (pen*Treatment (Season)) + Q (Season,Treatment*Season)
Treatment*Season	2	123.345114	61.672557	Var (Residual) + 4.2577 Var (pen*Treatment (Season)) + Q (Treatment*Season)
pen*Treatment(Season)	6	1015.980284	169.330047	Var (Residual) + 4.3651 Var (pen*Treatment (Season))
Residual	42	1686.215991	40.148000	Var (Residual)

85

Type 3 Analysis of Variance

Source	Error Term	Error DF	F Value	Pr > F
Treatment	0.9754 MS (pen*Treatment (Season)) + 0.0246 MS (Residual)	6.0719	1.34	0.3289
Season	0.9646 MS (pen*Treatment (Season)) + 0.0354 MS (Residual)	6.1048	4.76	0.0711
Treatment*Season	0.9754 MS (pen*Treatment (Season)) + 0.0246 MS (Residual)	6.0719	0.37	0.7046
pen*Treatment (Season)	MS(Residual)	42	4.22	0.0021

Covariance Parameter Estimates

Cov Parm	Estimate
pen*Treatment (Season)	29.5944
Residual	40.1480

Fit Statistics

-2 Res Log Likelihood	335.4
AIC (smaller is better)	339.4
AICC (smaller is better)	339.7
BIC (smaller is better)	340.4

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Treatment	2	6.09	1.26	0.3481
Season	1	6.1	5.06	0.0648
Treatment*Season	2	6.09	0.33	0.7320